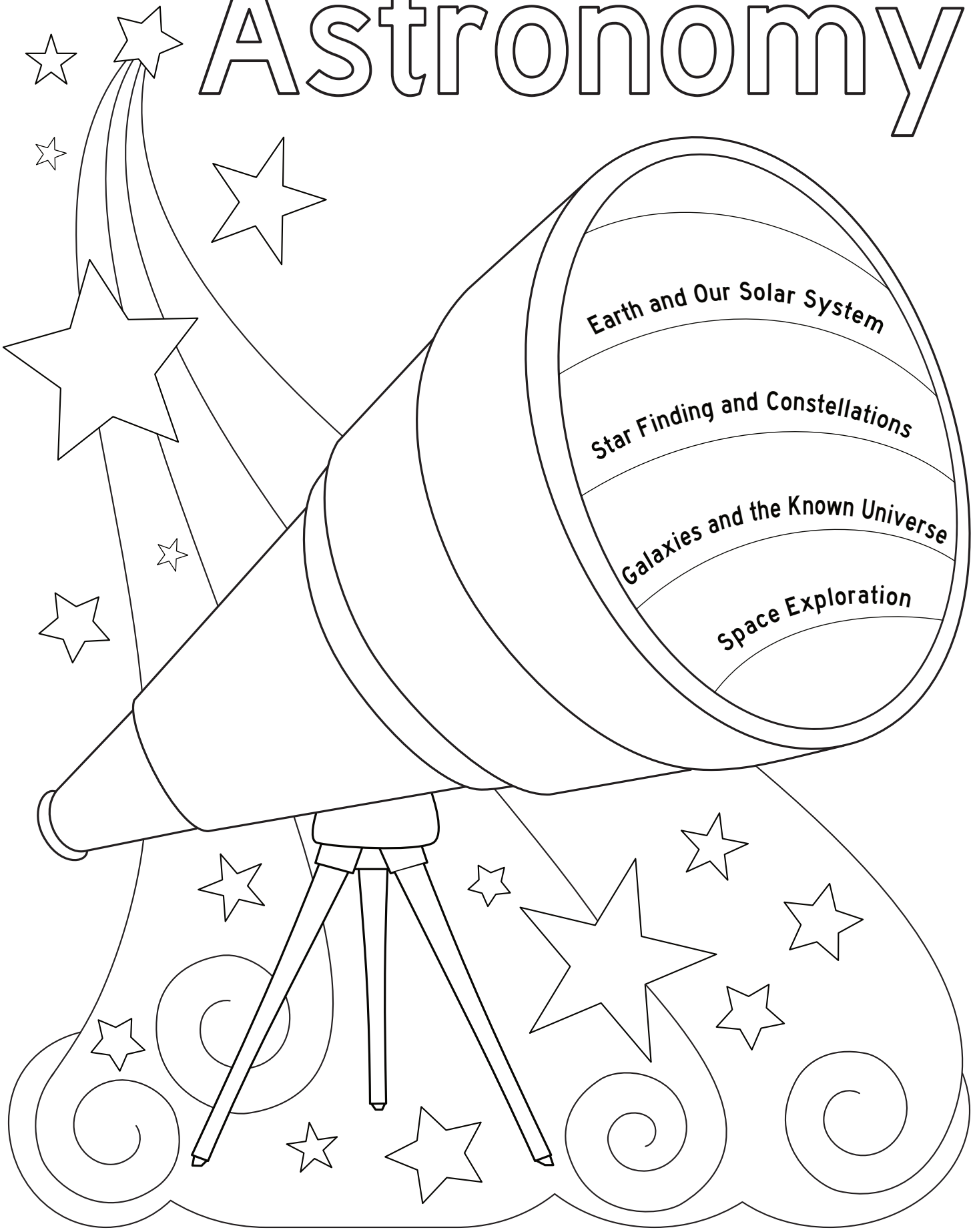
Astronomy


Earth and Our Solar System
Star Finding and Constellations
Galaxies and the Known Universe
Space Exploration

ASTRONOMY

Unit	Lesson	Date	Topic	Pages
Unit 1. Earth and the Moon	1	Mon, Jan 13	What Is Astronomy?	4-7
	2	Wed, Jan 15	Diurnal Motion	8-9
	3	Self paced lesson	Measure Your Latitude	10-13
		Mon, Jan 20	No Class (MLK day holiday)	
	4	Wed, Jan 22	The Seasons	14-15
	5	Self paced lesson	DIY Equatorial Sundial	16-17
	6	Mon, Jan 27	Lines of Latitude	18-19
	7	Wed, Jan 29	Our Moon	20-21
	8	Self paced lesson	Cookie Models and Journal	22-25
	9	Mon, Feb 3	Eclipsed	26-27
	10	Wed, Feb 5	Totality	28-29
	11	Self paced lesson	Earth and Moon Review/Assessment	30-33
	12	Mon Feb 10	EARTH & MOON QUIZ SHOW	
Unit 2. Our Solar System	13	Wed Feb 12	Our Solar System	34-35
	14	Self paced lesson	Step Scale Model of the Solar System	36-37
	15	Mon Feb 17	Inner vs Outer Planets	38-39
	16	Wed Feb 19	Planetary Motion	40-41
	17	Self paced lesson	Ellipses & Orbits	42-43
	18	Mon Feb 24	Dwarf Planets and Moons	44-45
	19	Wed Feb 26	Asteroids, Comets, and Meteors	46-47
	20	Self paced lesson	Flour and Cocoa Craters	48-49
	21	Mar 3	Near Earth Objects	50-51
	22	Mar 5	SOLAR SYSTEM QUIZ SHOW	
	23	Self paced lesson	Solar System Review/Assessment	52-55
Spring Break is March 10-15				
Unit 3: Stars, Galaxies, and the Universe	24	Mar 17	Constellations	56-59
	25	Mar 19	Stargazing 101	60-61
	26	Self paced lesson	Stargazing	62-67
	27	Mar 24	The Sun as a Star	68-69
	28	Mar 26	Solar Weather	70-71
	29	Self paced lesson	Solar Updraft Tower	72-73
	30	Mar 31	Main Sequence Stars	74-75
	31	Apr 2	Supernovas	76-77
	32	Self paced lesson	Star Classification Poster	78-81
	33	Mon, Apr 7	Black Holes	82-83
	34	Wed, Apr 9	Galaxies and our Local Neighborhood	84-85
	35	Self paced lesson	Constellation Viewer	86-87

Unit	Lesson	Date	Topic	Pages
Unit 3	36	Mon, Apr 14	Spacetime and the Universe	88-89
	37	Wed, Apr 16	Dark Matter	90-91
	38	*Self paced lesson*	Review for Quiz Show	92-95
	39	Mon, Apr 21	STARS, GALAXIES, & UNIVERSE QUIZ SHOW	
Unit 4: Space Exploration & Mysteries	40	Wed, Apr 23	Telescopes	96-97
	41	*Self paced lesson*	Candybar Heat Shield	98-99
	42	Mon, Apr 28	Lunar Missions	100-101
	43	Wed, Apr 30	Exploring Space	102-103
	44	*Self paced lesson*	Review for Quiz Show	104-109
	45	Mon May 5	FINAL QUIZ SHOW	
			Appendix	110-121

Supply List:

Lesson 3 - Measure Your Latitude
- Thread or string (about 15 cm long)
- Printable protractor OR standard protractor
- Pin OR a needle or nail
- Washer OR small object that can hang from string
- Straw
- Tape and a tape measure

Lesson 6 - DIY Equatorial Sundial
- Inclinometer (made in lesson 3)
- Wooden Dowel
- Drill
- Cardboard or wood
- Sundial template
- Scissors

Lesson 8 - Make a Model of Earth & the Moon
- Dough OR modeling clay
- Ruler (optional)

Lesson 9 - Cookie Models and Journal
- Moon journal printout
- Binoculars (optional)
- Cookie and cream style sandwich cookies (optional)

Lesson 15 - Step Scale Model of Solar System
- Chalk or something else that can be used to mark position in an outdoor location
- Planet template OR modeling clay
- Yardstick or tape measurer (optional)

Lesson 18 - Ellipses and Orbits
- Thread OR string
- 2 pushpins OR small nails
- Marker OR pen
- Flat piece(s) of cardboard

Lesson 21 - Flour and Cocoa Craters
- 2 balls of different sizes such as small / large marbles
- Flour
- Cocoa powder
- Ruler
- A wide non-breakable container

Lesson 26 - Stargazing
- Outdoor location
- Warm clothing
- Binoculars or telescope (optional)
- Red flashlight (or light covered with something red)
- Stargazing printouts or paper and pencil

Lesson 29 - Solar Updraft Tower
- Paper (in both black and white colors)
- 2 wooden skewers
- Scissors
- Tape
- 2 needles OR 2 nails
- Modeling clay
- Thermometer
- Sunny window OR a heat lamp

Lesson 32 - Star Classification Poster
- Poster board or a large piece of paper
- Art supplies such as markers, crayons, or paint
- Objects to represent stars that are different sizes and colors such as:
  - *Paper stars. use scissors to cut different colors of construction paper to different sizes*
  - *Balloon stars: inflate different-color balloons to different sizes*
  - *Papier-mâché stars: use a variety of bowls as molds to make hemispheres of different sizes*

Lesson 35 - Make a Constellation Viewer
- Cylindrical cardboard container
- Constellation printout
- Nail or pin
- Phone (with a flashlight)

Lesson 41 - Candybar Heat Shield
- 4 paper cups
- Tongs
- Small candy bars
- Construction materials such as cotton balls, steel wool, newspaper, cardboard, or aluminum foil
- Electrical tape
- Hair dryer

Unit 1: Earth & the Moon

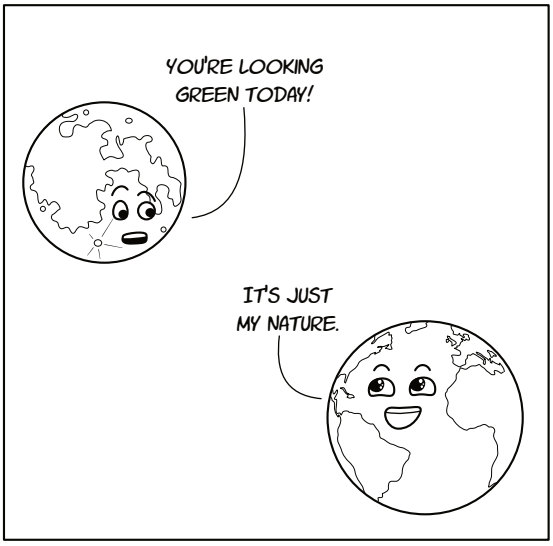
Words are more than tools for communication, they are the framework of knowledge! Without language to express and define new ideas, we wouldn't be able to learn.

To understand astronomy, it's essential to have the right **vocabulary**. The words you see on these pages are terms we will be using in our Earth and Moon unit.

Are you already familiar with some of these terms? If so, match them with the correct vocab cards.

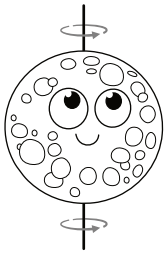
If there are terms or words you don't know, don't worry! We'll be learning them in future lessons. As you learn new concepts, come back to these pages and label each card.

You can also become more familiar with these words by using flashcards or playing memory. The appendix has a printer-friendly set of all of the vocabulary terms.



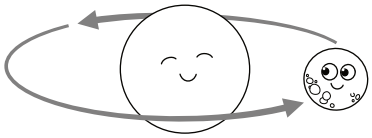
APHELION	DIURNAL MOTION	ECLIPSE	ECLIPTIC	EQUATOR
HEMISPHERE	HORIZON	LATITUDE	LONGITUDE	ORBIT
PERIHELION	PRIME MERIDIAN	REVOLVE	ROTATE	ZENITH

TO SPIN AROUND AN AXIS OR CENTER



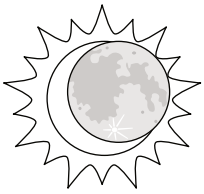
ROTATE

TO MOVE IN A CIRCULAR PATH AROUND AN OBJECT; TO ORBIT AROUND SOMETHING



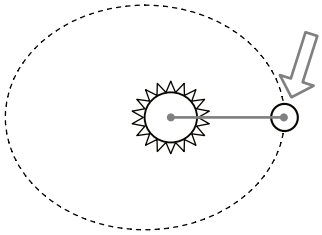
REVOLVE

WHEN ONE OBJECT PASSES IN FRONT OF ANOTHER; WHEN ONE OBJECT PARTIALLY OR TOTALLY BLOCKS THE VIEW OF ANOTHER OBJECT



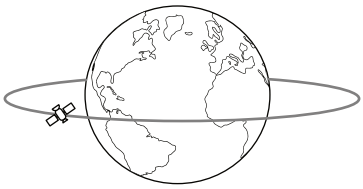
ECLIPSE

THE POINT WHERE AN ORBITING OBJECT IS CLOSEST TO THE SUN



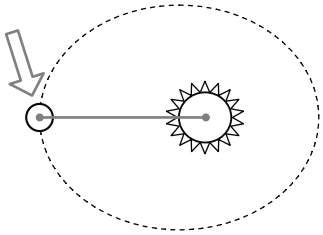
PERIHELION

THE CURVED PATH AN OBJECT TAKES AROUND A STAR, PLANET, OR MOON



ORBIT

THE POINT WHERE AN ORBITING OBJECT IS FURTHEST FROM THE SUN

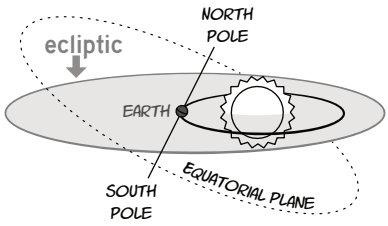


APHELION

A LINE FROM NORTH TO SOUTH POLE THAT PASSES THROUGH GREENWICH, ENGLAND

PRIME MERIDIAN

THE APPARENT PATH OF THE SUN ACROSS THE SKY OVER A YEAR



ECLIPTIC

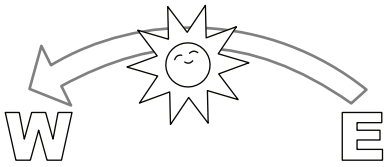
A LINE AROUND THE EARTH THAT IS EQUALLY DISTANT FROM THE NORTH / SOUTH POLES.

EQUATOR

PARALLEL LINES THAT MEASURE DISTANCE FROM THE EQUATOR

LATITUDE

THE REPEATED DAILY MOVEMENT OF STARS AND OTHER OBJECTS ACROSS EARTH'S SKY FROM EAST TO WEST



DIURNAL MOTION

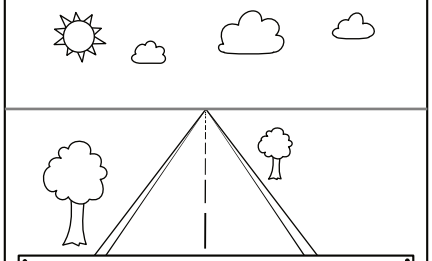
LINES THAT MEASURE DISTANCE FROM THE PRIME MERIDIAN

LONGITUDE

THE POINT IN THE SKY THAT IS DIRECTLY ABOVE THE OBSERVER

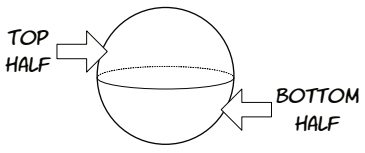
ZENITH

THE LINE WHERE THE SKY AND EARTH APPEAR TO MEET



HORIZON

HALF OF A SPHERE



HEMISPHERE

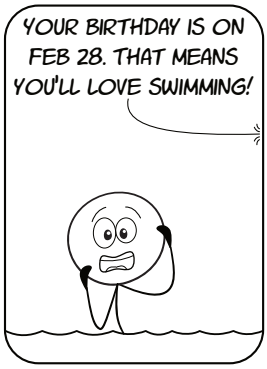
What is Astronomy?

People sometimes confuse astronomy and astrology. These two fields share a common history, but today they are very different!

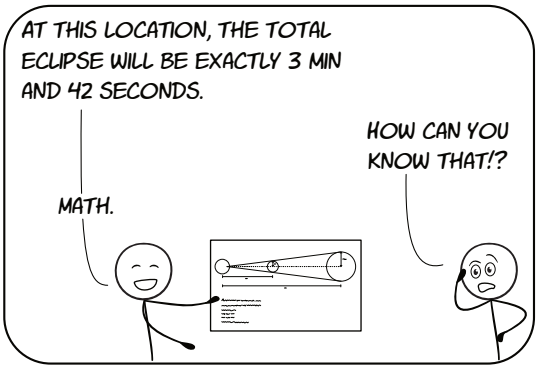
Astronomy is: A BRANCH OF SCIENCE FOCUSED ON UNDERSTANDING THE OBJECTS AND MATTER BEYOND EARTH'S ATMOSPHERE. IT IS EVIDENCE-BASED.

Astrology is: A SET OF IDEAS AND SUPERSTITIONS ABOUT HOW THE POSITION OF STARS AND PLANETS INFLUENCE HUMANITY. IT IS NOT EVIDENCE-BASED (IT'S A PSEUDOSCIENCE).

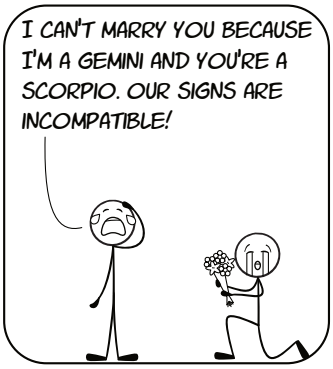
IS IT ASTRONOMY OR ASTROLOGY? Label each scenario below:



ASTROLOGY



ASTRONOMY



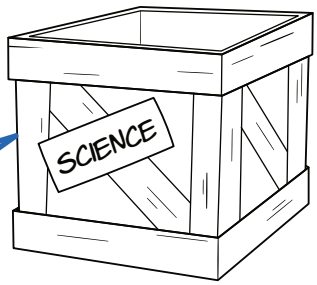
ASTROLOGY

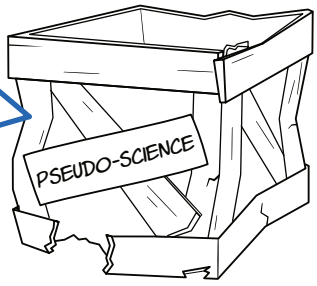
ASTROLOGY

IS IT SCIENCE OR PSEUDOSCIENCE?

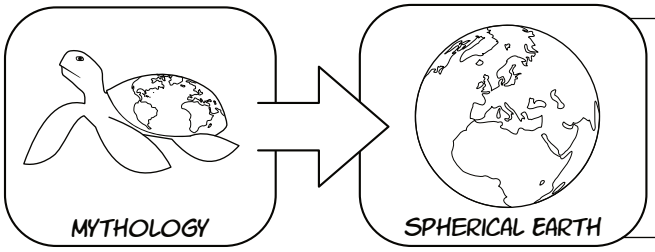
Match each characteristic with the appropriate box

- Relies on anecdotal evidence
- Relies on data, controlled studies, and reproducible observations
- Responds to contradictions & criticism by gathering additional data or revising ideas
- Responds to contradictions & criticism with denial, antagonism, or conspiracy theories





Concepts of Earth through Human History



In ancient times, many cultures had mythology depicting the Earth as being flat or being part of a giant tree or on the back of a large animal.

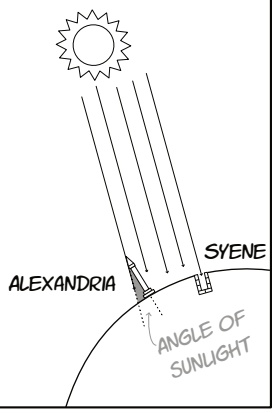
Using reason and mathematics, Greek philosophers proved the Earth was spherical. Some of them also recognized that Earth behaved like the other planets and orbited the Sun.

Aristotle
approximately 350 BCE

Aristotle observed that Earth cast a circular shadow on the moon during a lunar eclipse, which meant the Earth was spherical.

Eratosthenes
approximately 250 BCE

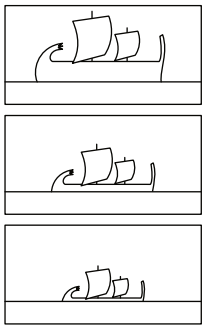
Eratosthenes famously measured shadows in both Syene and Alexandria on the summer solstice. Using geometry, he then calculated the circumference of the Earth. His answer was surprisingly accurate!



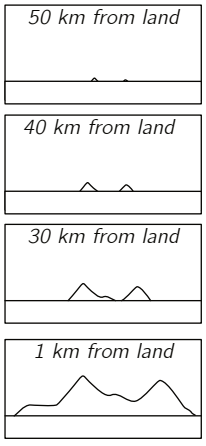
Ptolemy
approximately 150 CE

Observations from ships at sea were consistent with a curved body of water. Ships disappear hull-first when sailing over the horizon. Conversely, land appears "top first" when viewed from someone who is out at sea.

A SHIP DISAPPEARS HULL-FIRST WHEN IT SAILS OVER THE HORIZON



LAND APPEARS "TOP FIRST" WHEN COMING HOME FROM SEA



Our Current View of Earth:

Earth is an oblate ellipsoid! It's spinning motion makes it about 44 km wider at the equator than at the poles.

Diameter ~ 12,756 km (Equator) or ~ 12,712 km (pole-to-pole).

Day length = 23 hours and 56 minutes.

Year length = 365.25 days

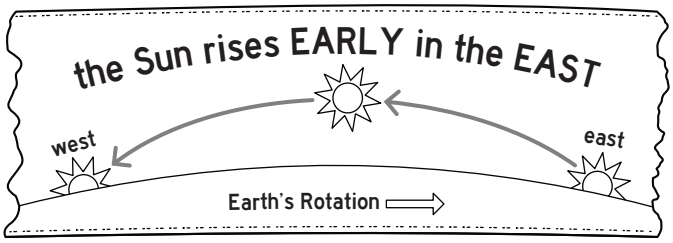
Distance from Sun = 150 million km (also called 1 Astronomical Unit or AU)

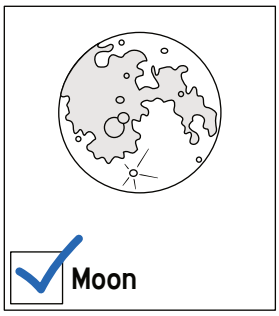
If the Sun were as tall as a typical front door, Earth would only be the size of a nickel.

Diurnal Motion: resulting from the rotation of the Earth

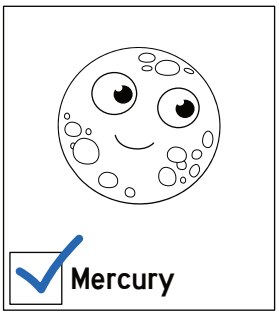
From the perspective of an observer on Earth, the Sun moves in an arc across the sky each day from east to west.

What other objects follow a similar path through the sky? Put a checkmark by all that apply:

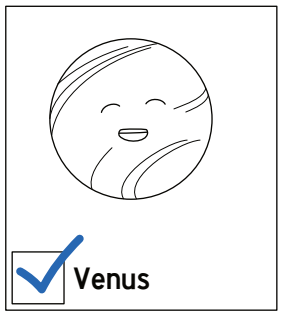




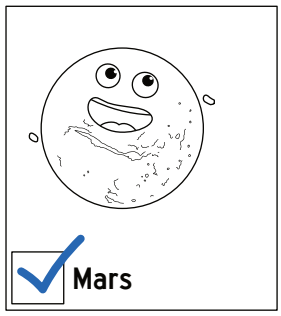
☑ Moon



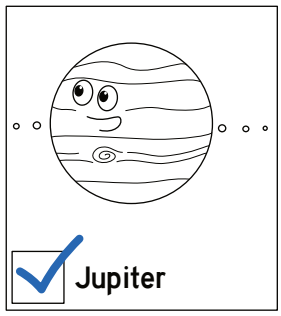
☑ Mercury



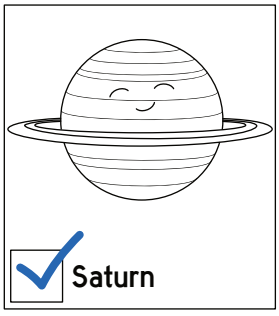
☑ Venus



☑ Mars

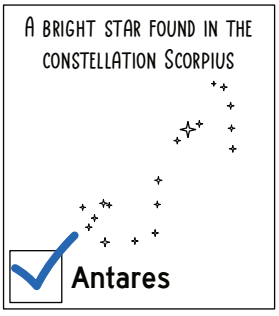


☑ Jupiter

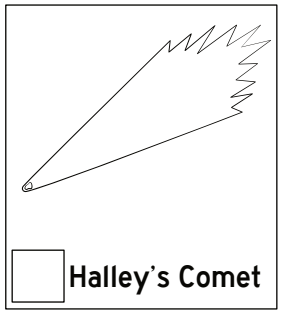


☑ Saturn

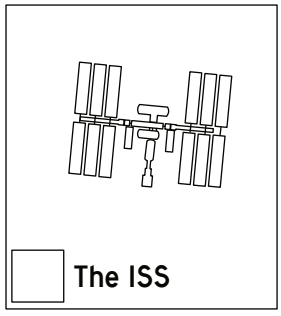
A BRIGHT STAR FOUND IN THE CONSTELLATION SCORPIUS



☑ Antares

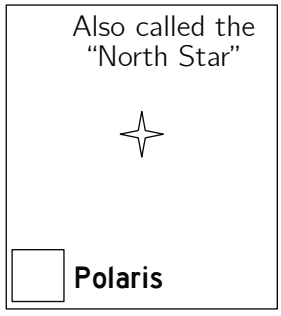


☐ Halley's Comet



☐ The ISS

Also called the "North Star"

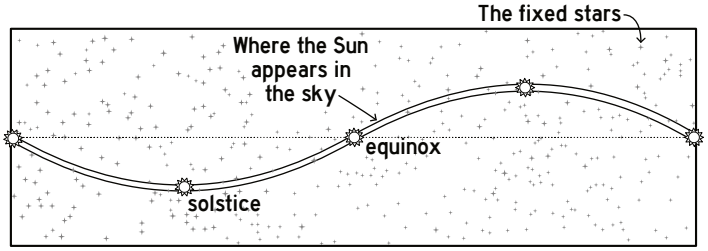


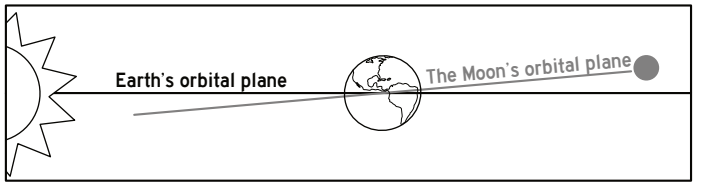
☐ Polaris

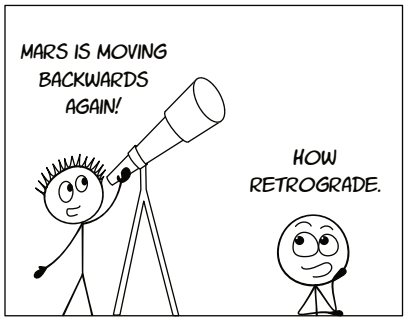
Over the course of a year, the Sun appears to travel through the fixed stars, tracing a path called the **ecliptic**.

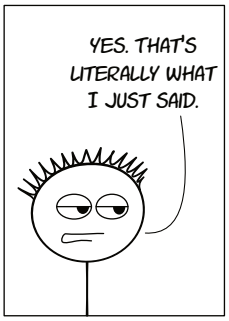
Early Greek astronomers named this line the *ecliptic* (Greek for "fail to appear") because it was the only place where eclipses occurred.

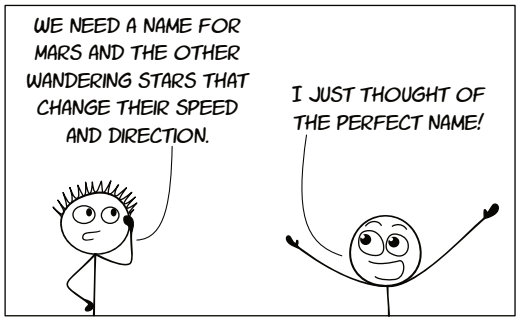
Another way to think about the ecliptic is from the perspective of an observer in outer space. In this case, the ecliptic is the plane of Earth's orbit around the Sun.

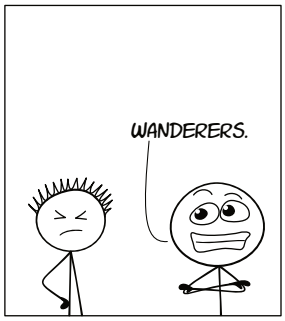








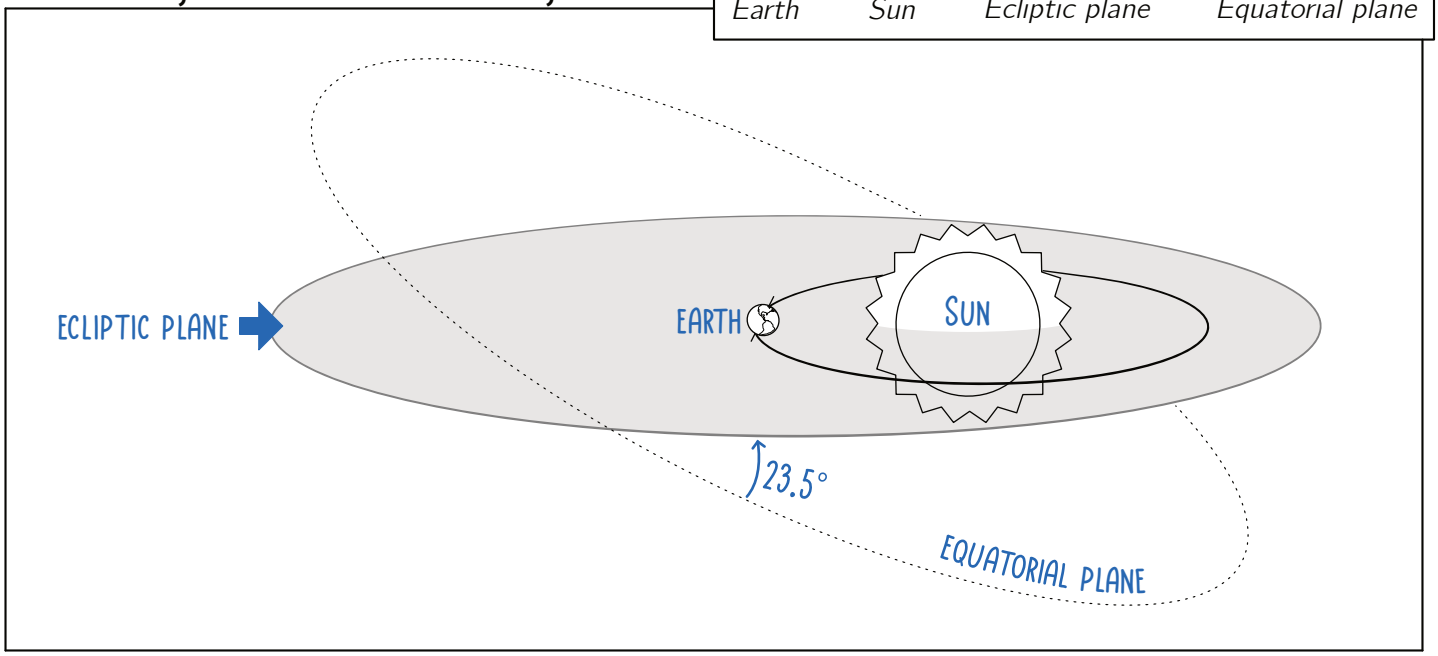




The English word "planet" comes from the Greek word planētēs which means "wanderer."

Label the diagram below with the following terms:

Earth	*Sun*	*Ecliptic plane*	*Equatorial plane*



The poles, equator, lines of latitude, and lines of longitude are all defined in relation to how our planet **rotates**. Rotating is different than revolving!

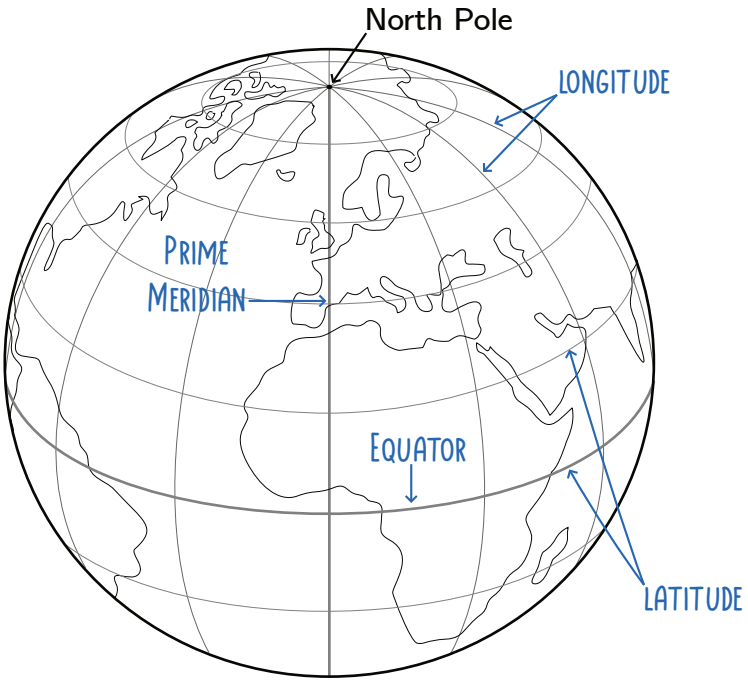
Define these terms and describe how long it takes the Earth to complete one of each:

Rotation: To spin or move around an axis or center. Earth completes one rotation in approximately 24 hours.

Revolution: To move in a circular path around an object. It takes Earth 365.25 Days to complete one revolution around the Sun. The extra quarter of a day is why we have a "leap year" every 4 years.

Label the term for each definition and then identify them on the globe:

The first one has been done as an example



Pole (North or South Pole)

A point aligned with Earth's axis of rotation, or a point around which all the stars appear to rotate.

Equator

A line around the Earth that is equidistant from each pole. A circle that divides a sphere into northern and southern hemispheres.

Lines of latitude

Parallel lines that measure distance from the equator.

Prime Meridian

A line from the North Pole to the South Pole that passes through Greenwich, England.

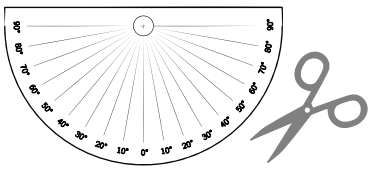
Lines of longitude

Lines that measure distance from the prime meridian.

Measure Your Latitude

MATERIALS

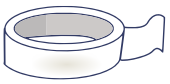
~15 cm of thread or string



Protractor template and scissors OR a standard protractor

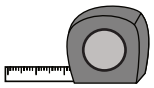
Pin

Washer or other weight



Tape

1 straw



Tape measurer

GOALS

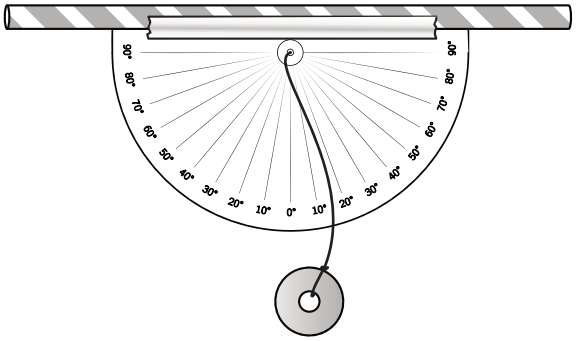
- Build a device to measure the angle of incline of a distant object.
- Find the latitude of your current location.

Purpose of an inclinometer

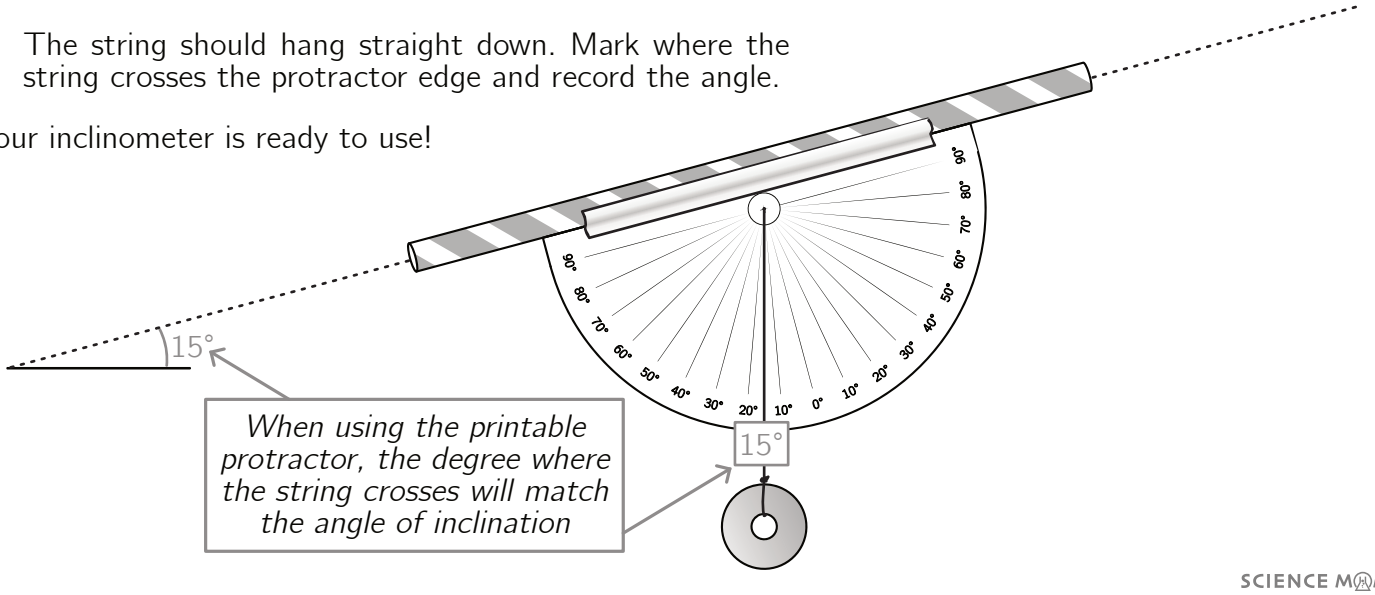
An inclinometer (sometimes called clinometer) is a tool that helps you to measure the angle or inclination of an object. With a little bit of geometry, inclinometers can be used to find the height of an object or the latitude of a person's current location.

How to make an inclinometer:

1. Use the protractor template from the appendix to make a printable protractor OR use a standard protractor. If using the printable version, be sure to cut it out carefully so that you get a straight edge on top. If necessary, glue it to cardstock or cardboard to make it more sturdy.
2. Use a pin to poke a hole in the center of the protractor template on the plus sign.
3. Feed some of the the string through the hole and tape it in place on the back. If using a standard protractor, tape the string so that it hangs freely.
4. Tie the washer to the other end of the string.
5. Tape the straight edge of the protractor to the straw.
6. To use the inclinometer, close one eye and look at your target through the straw. Carefully adjust the angle so that you can see the target in the center of the straw.
7. The string should hang straight down. Mark where the string crosses the protractor edge and record the angle.

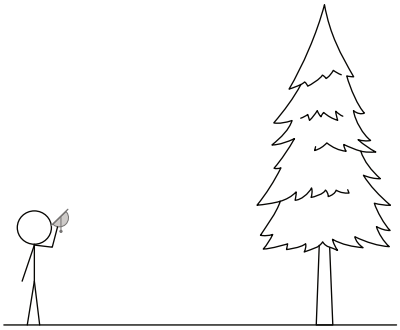


Your inclinometer is ready to use!



How tall is it?

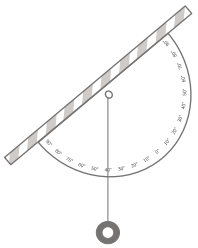
Before finding our latitude, it's important to understand how an inclinometer works by using it to find the height of an object.



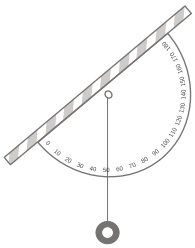
1. Choose a tall object such as a tree, flagpole, or building that is located on flat ground.
2. Have a person (the observer) stand so that they have a clear line of sight to the object.
3. The observer should look through the straw of the inclinometer and hold it so that the top of the object is visible through the center of the straw.
4. Note where the string is hanging and record where it crosses the curved edge of the protractor. Record the angle.
   - *If using the **printable protractor,** record the number seen where the string crosses the edge.*
   - *If using a **standard protractor**, subtract the angle measured on the protractor from 90°. This is your angle of inclination.*
5. Measure the horizontal distance from observer to object.
6. Measure the eye height of the observer.
7. Now that you have both the angle and horizontal distance of a triangle, you can use trigonometry to find the length of the side opposite the angle. This distance (labeled x) is from the eye height of the observer to the top of the object. Use your angle and horizontal distance to find the value of x:

   x = tangent(angle of inclination) · horizontal distance

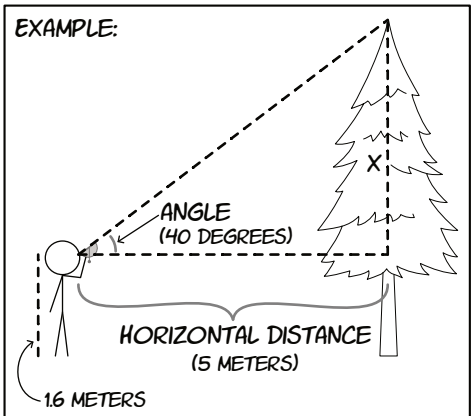
8. Add the height of the observer to x to find the total height of the object.



PRINTABLE PROTRACTOR
Angle of inclination: 40°



STANDARD PROTRACTOR
Angle of inclination:
90°-50° = 40°



x = tan(40°)·5
x = 4.2 meters
Tree height = 4.2 + 1.6 = **5.8 meters**

What object did you choose to measure? How tall do you think it is? Before using the inclinometer, make a guess! What do you estimate for the height of the object?

Object: _____

Estimated height before measuring: _____

Horizontal distance (observer to object): _____

Eye level height of observer: _____

Angle of inclination: _____

Calculated height of the object: ☐

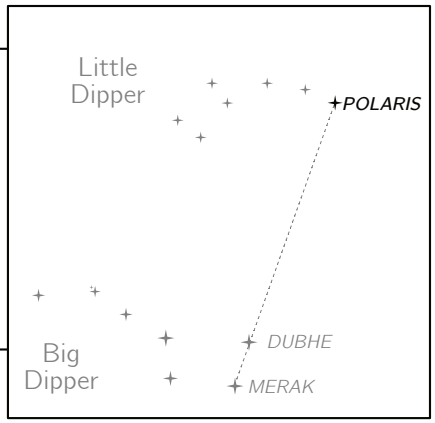
x = tangent(angle of inclination)·horizontal distance

x + eye level height of observer = object height

Finding Your Pole Star: Northern Hemisphere

Locate Polaris (the North Star) by using an app such as Sky Guide or by using the asterism called the Big Dipper. The stars Merak and Dubhe in the Big Dipper point directly toward Polaris, which is the end of the "handle" in the Little Dipper.

To find your latitude with the inclinometer, look at Polaris through the straw. Hold the inclinometer steady with the string hanging freely down. Note where the string crosses the curved edge of the protractor.



Finding Your Pole Star: Southern Hemisphere

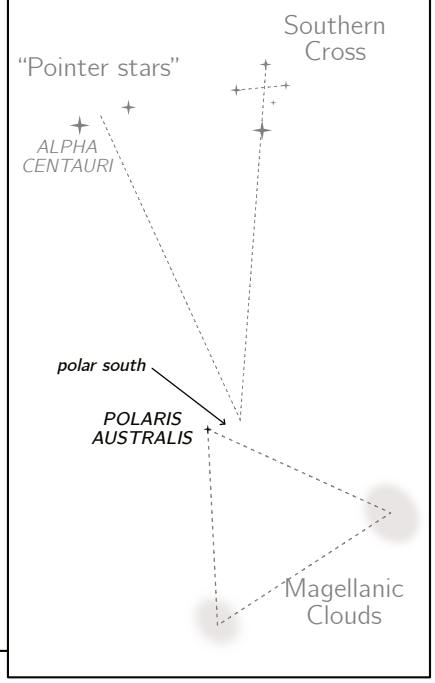
Use the inclinometer to find your latitude by locating Sigma Octantis (also called Polaris Australis or the Southern Star). It is not located exactly over polar south, but it's close! You can use an app such as Sky Guide or find it by using one of these approaches:

1. Southern Cross + 4 Lengths: Find the Southern Cross. Notice the length between the stars that form the "long" end of the cross. Polaris Australis is approximately 4 of these lengths away along the same line.

2. The "Pointer Stars" and the Southern Cross: The two brightest stars in the constellation Centaurus are near the Southern Cross. A line perpendicular to those stars can be used to intersect a line from the Southern Cross. Polaris Australis is very close to this intersection.

3. Magellanic Cloud Triangle: The large and small Magellanic clouds are two nearby galaxies that are visible as hazy spots in a dark night sky (similar in appearance to the hazy light of the Milky Way). A nearly equilateral triangle can be drawn between these and Polaris Australis.

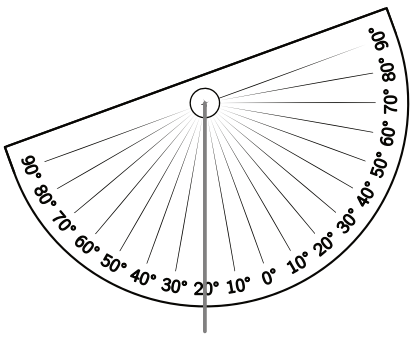
To find your latitude with the inclinometer, look at Polaris Australis, through your straw. Hold the inclinometer steady with the string hanging freely down. Note where the string crosses the edge of the protractor.



The **printable protractor** has angles labeled with 90°−x. Where the string crosses the edge will match the protractor's ***angle of inclination***.

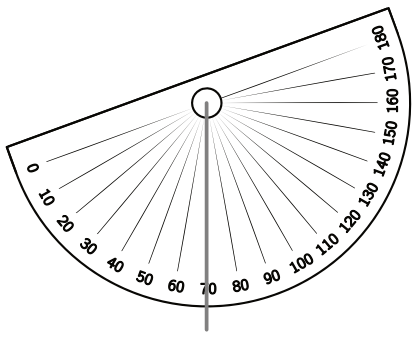
If using a **standard protractor**, take the angle where the string crosses the edge and then subtract it from 90°. Now you have found the ***angle of inclination***.

EXAMPLE WITH PRINTABLE PROTRACTOR:



The string crosses at 20°, so the angle of inclination to the pole star and latitude are also 20°. If in the Northern Hemisphere, the latitude would be 20° North. In the Southern Hemisphere, the latitude would be 20° South.

EXAMPLE WITH STANDARD PROTRACTOR:



The string crosses at 70°, so the angle of inclination is 90°-70°= 20°. If in the Northern Hemisphere, the measured latitude would be 20° North. If in the Southern Hemisphere, the latitude would be 20° South.

1. Why should the angle of inclination to the pole star be equal to an observer's latitude on Earth? Use the diagram if it is helpful to your answer.

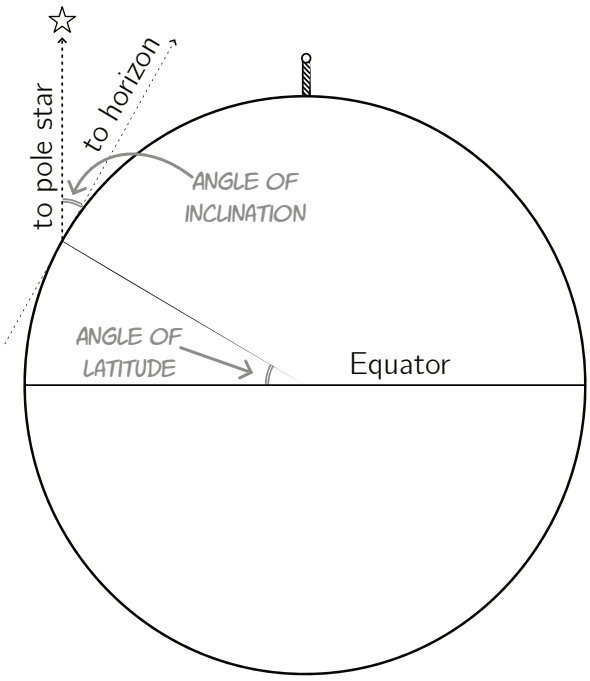
   Latitude is the angular distance from the equator.

   It's measured by taking the angle between the horizon and Earth's axis of rotation (north/south poles).

   When you observe a pole star such as Polaris, the angle it makes above the horizon corresponds to how far you are north of the equator (your latitude).

   At the North Pole, Polaris is directly overhead (ninety degrees above the horizon)

   At the Equator, Polaris lies at the horizon (0° above the horizon).



2. At your location, what angle of inclination did you observe when sighting the pole star (Polaris or Polaris Australis)?

   Answers will vary depending on location.

   Don't forget to adjust how you read the angle according to which type of protractor you're using!

3. Look up your actual latitude. Did the angle of inclination match your latitude? If not, what do you caused the difference?

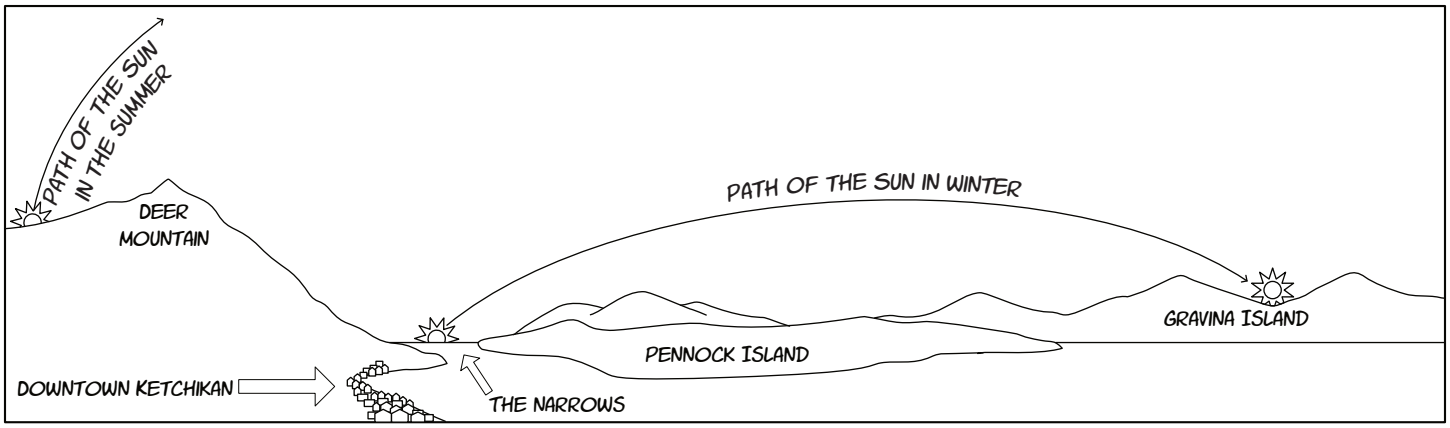
   Answers will vary depending on location. If either Polaris or Polaris Australis was successfully sighted, then the angle of inclination should be within a few degrees of the actual latitude. Small errors in reading the angle can cause the inclinometer reading to be different from actual latitude. Also, the closer one is to the equator, the lower the star will be in the sky. Atmospheric haze or refraction can interfere with the sighting.

4. Siti lives on a small island in Indonesia located very close to the equator. Will she be able to use an inclinometer to find her latitude? Why or why not?

   Most likely, Siti will NOT be able to use an inclinometer to see Polaris or Polaris Australis. While both stars would be on the horizon, it would be difficult to see them due to atmospheric haze and refraction.

   This activity could be difficult or even impossible for anyone located between the latitudes of about 10° N and 10° S. The combination of atmospheric interference and obstacles on the horizon (land, buildings, or vegetation etc) make it much more difficult to get an accurate sighting of a pole star at those latitudes.

THE SEASONS: caused by Earth's axial tilt



During the winter in Ketchikan, Alaska, we watch the Sun rise over the Tongass Narrows. Sunset occurs over Gravina Island directly in front of our window. The Sun is low in the sky all day and never shines in our backyard.

During the summer, the Sun rises on the back side of Deer Mountain and our backyard has hours of sunshine. In the summer evenings, we can't see the sunset from our house. It's far to the right behind houses and mountains!

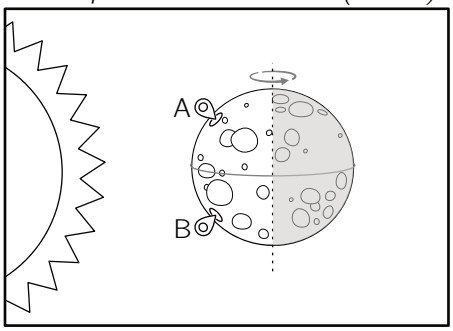
What seasonal differences in the position of the Sun have you observed where you live? When and where does the Sun rise and set? Where is the Sun in the sky at noon?

During winter: ANSWERS WILL VARY. MOST LOCATIONS SHOULD INCLUDE THE OBSERVATION THAT THE SUN IS LOWER IN THE SKY IN WINTER AND THERE ARE FEWER HOURS OF DAYLIGHT.

During summer: ANSWERS WILL VARY. MOST LOCATIONS SHOULD INCLUDE THE OBSERVATION THAT THE SUN IS HIGHER IN THE SKY AND THERE ARE MORE HOURS OF DAYLIGHT.

How much sunlight in 1 day?

Tilt of planet = almost none (0.027°)

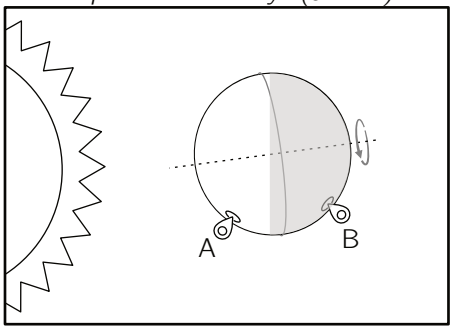


A planet with almost no tilt undergoes 1 complete rotation in 24 hours. During that time, will point A receive more, less, or the same amount of sunlight as point B? Point A and B are the same distance away from the equator.

POINT A WILL RECEIVE THE SAME AMOUNT OF SUNLIGHT AS POINT B (BOTH ABOUT 12 HOURS).

BONUS FACT: THE PLANET MERCURY HAS A TILT OF 0.027°

Tilt of planet = sideways (97.77°)

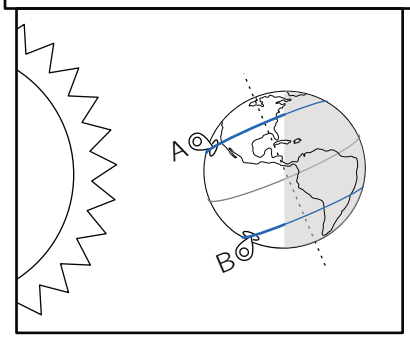


A planet with an extreme tilt of 97° undergoes 1 complete rotation in 24 hours. During that time, will point A receive more, less, or the same amount of sunlight as point B? Points A and B are the same distance away from the equator.

POINT A WILL GET MUCH MORE SUNLIGHT! POINT A WILL HAVE 24 HOURS OF SUNLIGHT AND POINT B WILL HAVE 24 HOURS OF DARKNESS.

BONUS FACT: THE PLANET URANUS HAS A TILT OF 97.77°

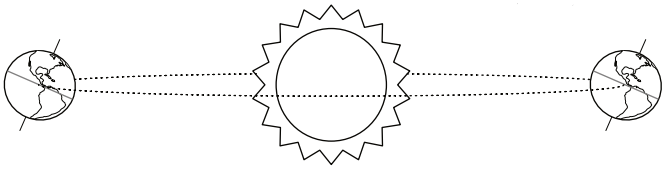
Earth is tilted at 23.5 degrees



Earth has a tilt of 23.5° and completes 1 rotation every 23 hours and 56 minutes. During that time, will point A receive more, less, or the same amount of sunlight as point B? Point A and B are the same distance away from the equator.

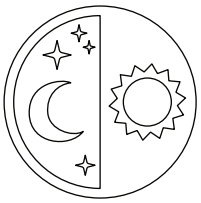
Point A will get more sunlight than point B. If paths are traced to show the path of each point (parallel to the equator) we can see that when the tilt is toward the Sun, A spends the majority of it's path in sunlight. The opposite for B: the majority of its path is during night.

Solstice



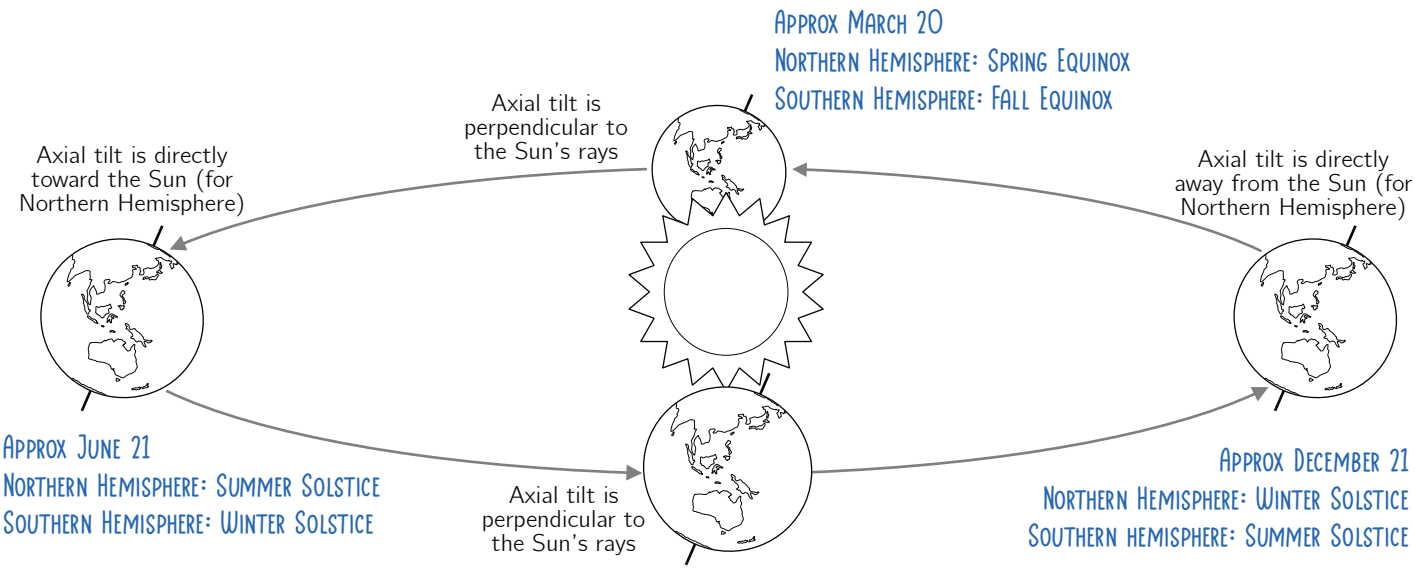
DEFINITION: The times of year when the Sun appears to reach either its highest or lowest point in the sky; When Earth's axis is pointed directly toward or away from the Sun

Equinox



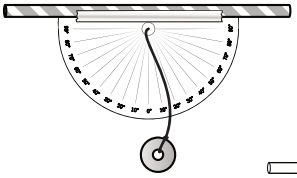
DEFINITION: The times of year when the Sun appears to pass directly over the equator. From the latin "aequi" which means equal and "nox" which means night.

Four points in Earth's orbit are described in the diagram below. Label each with the correct equinox or solstice for the Northern and Southern Hemisphere. Also include the approximate date.
Note that distance and size are not to scale.

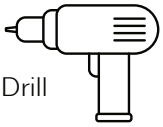


DIY Equatorial Sundial

MATERIALS

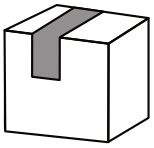


Inclinometer

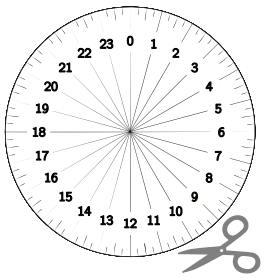


Drill

Wooden dowel



Cardboard or wood



Sundial template and scissors

GOALS

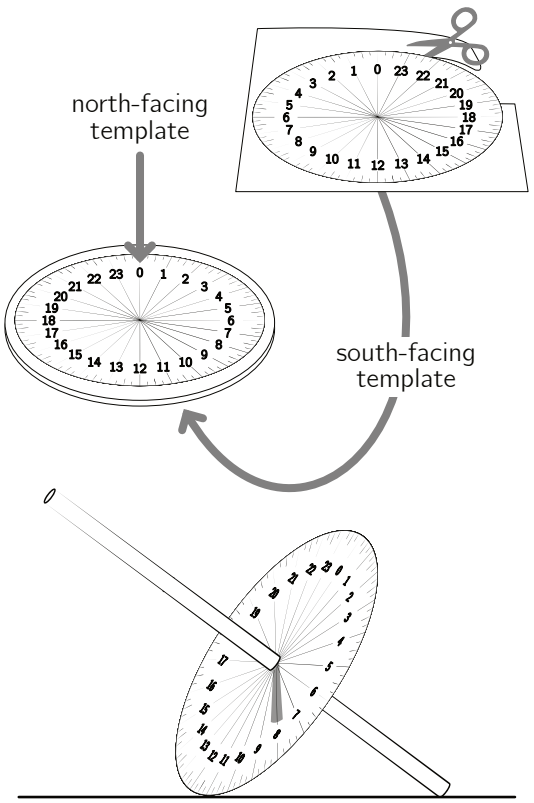
- Learn more about the Sun's path and Earth's orbit by building a working sundial.
- Adjust your sundial to give accurate time by considering various factors.

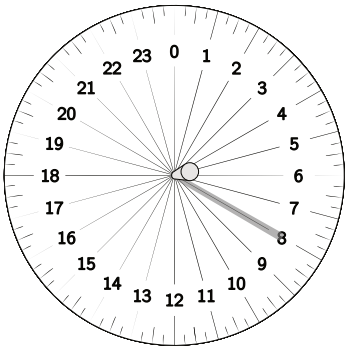
What's an Equatorial Sundial?

An equatorial sundial uses a shadow stick (gnomon) to cast a shadow on a circular dial. The dial is placed so that it's parallel to the Earth's equator. As long as it's properly aligned, it can be used anywhere on Earth!

How to make an equatorial sundial:

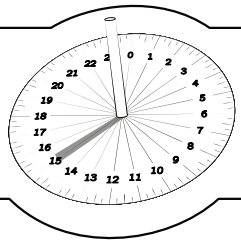
1. Print both the north-facing and south-facing printouts from the appendix and cut them out.
2. Glue or tape them to a solid backing such as cardboard. The backing should be sufficiently thick and rigid so that it can hold a rod perpendicular to the face of the dial without tipping. Be sure that the 0s are aligned.
3. Drill a hold in the center of the dial so that the dowel fits snugly in the hole but can be slid in or out.
4. If you are in the Northern Hemisphere, point the dial so that the gnomon is pointed directly at Polaris. (If you are in the Southern Hemisphere, point the gnomon to Polaris Australis.) Secure the gnomon so it remains pointed toward a pole star. Note that geographic or true north/south is different than magnetic north or south which you would get from a compass.
5. Use your inclinometer to check that the angle of your gnomon matches your latitude.
6. Rotate the dial so that the center of the shadow shows the correct time on the sundial. For example, if it is 8 in the morning, rotate the dial so the shadow is over 8. If it is 2 in the afternoon, rotate your sundial so the shadow is over the 14. Be sure the gnomon remains pointed at geographic north/south as you make adjustments.
7. Observe the shadow on your sundial for one or more days. Does it continue to give the correct time?





Does the dial of a sundial need to be tilted?

It's possible to design a sundial that is flat on the ground, but it must be based on an elliptical shape, and the gnomon must be moved to a different location each day. To learn more about other sundials, look up "horizontal sundials" and "analemmatic sundials."



1. When you placed your sundial outside, did it accurately tell the time? Check on it over several days or weeks to see how it does. What factors might cause discrepancies between the sundial time and standard clock time?

   There are several items that might cause sundial time to differ from the time shown on a clock.

   - Daylight savings: this will shift the time by an hour.
   - Timezones: when deciding on timezones, it's a balance between setting the clock to match the solar experience (with noon being near the sun's zenith) and human convenience. People tend to want as few time zones to deal with as possible. Dials in different parts of the same timezone will need to be rotated differently to show the same time relative to the sundial.
   - The elliptical shape of the Earth's orbit causes the Earth to move faster when it is closer to the Sun (January) and slower when it is further from the Sun (July). So the Sun appears to move more quickly /slowly across the sky at different times of year. This can impact the solar time by up to 16 minutes.
   - Any error in the angle of the gnomon will cause a correspondingly large error in the time shown.

2. Would your sundial work if located at the North Pole or South Pole? Why or why not?

   The sundial would work at any location (if there's sunlight) as long as the gnomon is aligned to point at the North Star in the northern hemisphere or at Polaris Australis/geographic south pole in the southern hemisphere. There are working sundials north of the Arctic Circle in Svalbard and south of the Antarctic Circle at McMurdo Station in Antarctica. They both work, but only when sunlight is visible. In both locations, the sundials are not functional during polar night.

3. Why does a sundial in the Northern Hemisphere need to be aligned with geographic north rather than magnetic north?

   Geographic north is aligned with Earth's rotational axis. It's the point around which the Earth rotates. If the Sundial is aligned in any other direction, it will cause the sundial to be inaccurate. Magnetic north is close to geographic north, but it is not the same! It is different enough to cause significant errors in how the sundial reads.

4. What was the most interesting thing you learned doing this project? OR What challenge or obstacles did you encounter making your sundial and how did you address them?

   Answers will vary

LINES OF LATITUDE: significant circles

DECEMBER SOLSTICE

On the December solstice, Earth is tilted so the South Pole is angled toward the Sun. Observers around the South Pole experience "polar day" or the "midnight sun."

The border of this region where the Sun does not set below the horizon on December solstice is called the **Antarctic Circle**.

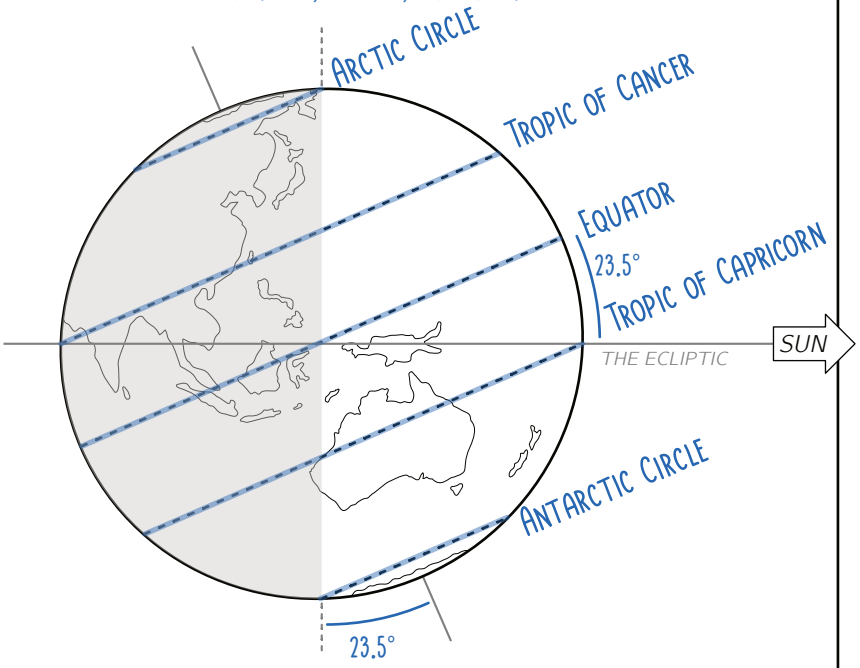
On the same day, observers in the region around the North Pole experience "polar night." The line of latitude surrounding this area is called the **Arctic Circle**.

These circles are defined as the latitudes where, during solstice, the center of the Sun remains continuously above or below the horizon for at least 24 hours.

On the December solstice, the latitude of 23.5° South intersects with the ecliptic. At this latitude, the Sun will be directly overhead. This southern most point where the Sun can appear directly overhead at noon is called the **Tropic of Capricorn** or "Southern Tropic." The word tropic comes from the Greek word *tropos*, meaning to turn.

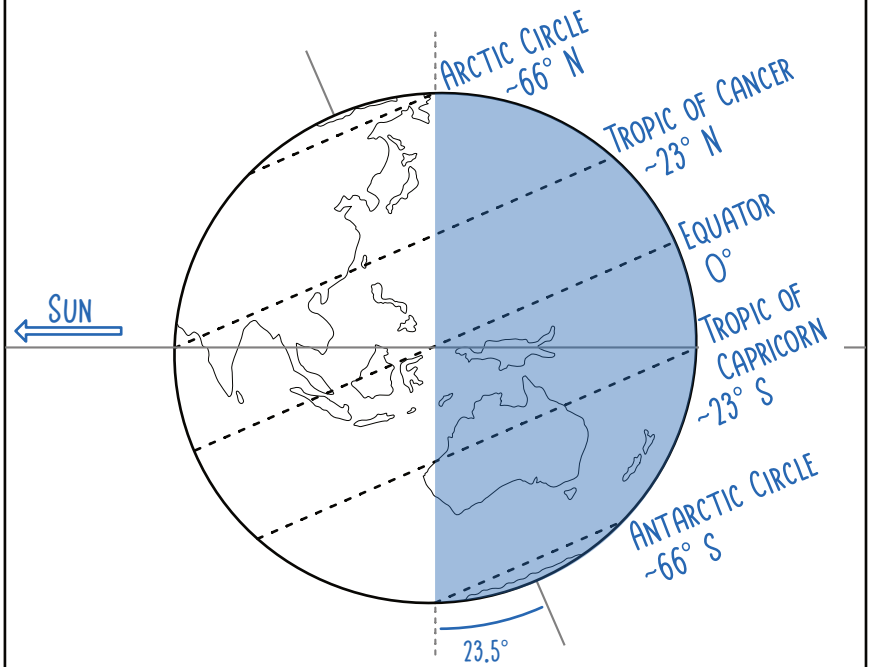
Label the dotted lines of latitude

*We round to the nearest half degree for Earth's tilt, but it's actually 23.44° instead of 23.5° and it's changing very slowly. In 10,000 years, it will be 22.1°



JUNE SOLSTICE

Draw an arrow to indicate the direction of the Sun and shade the hemisphere that would experience night. Label the dotted lines of latitude.



On the June solstice, what area of Earth will experience polar day?

Everything north of the Arctic circle

On the June solstice, what area of Earth will experience polar night?

Everything south of the Antarctic circle

At the equator, will the Sun be directly overhead during either solstice? Why or why not?

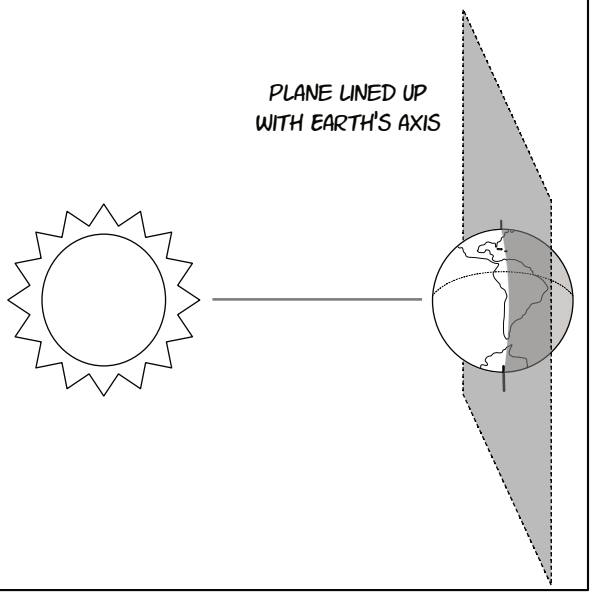
No. At the equator, the Sun appears north of the zenith on the June solstice and south of the zenith on the December solstice.

Fill in the blanks:

equal	equinox	location	overhead	perpendicular	terminator

During each EQUINOX, the tilt of the Earth is PERPENDICULAR to the line between the Sun and Earth. Equinoxes are the only time of year when the Sun appears to be directly OVERHEAD at the equator.

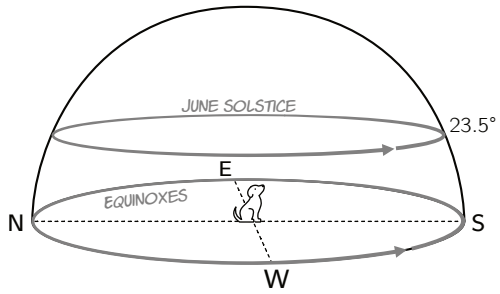
When the solar TERMINATOR or "edge" between night and day is perpendicular to the equator, it causes a cool effect: Each equinox, almost every LOCATION on Earth experiences EQUAL hours of light and darkness.



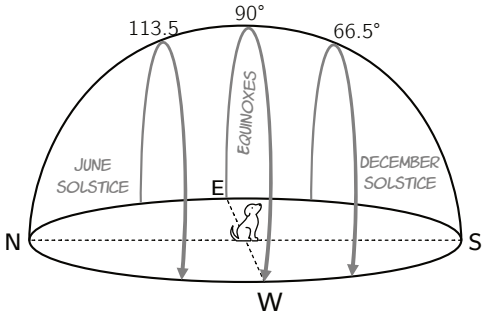
SOLSTICE vs EQUINOX Views from the ground

The hemispheres below show the view of the Sun's path in the sky at solstices and equinoxes. Label each with the correct location for the observer.

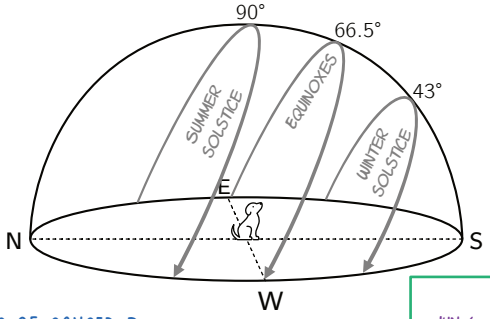
Locations could be: Arctic Circle, Antarctic Circle, equator, North Pole, South Pole, Tropic of Cancer, or Tropic of Capricorn.



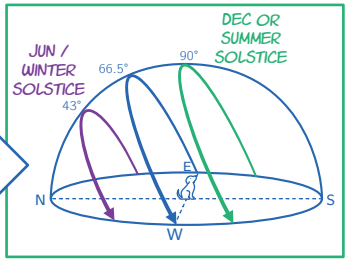
NORTH POLE

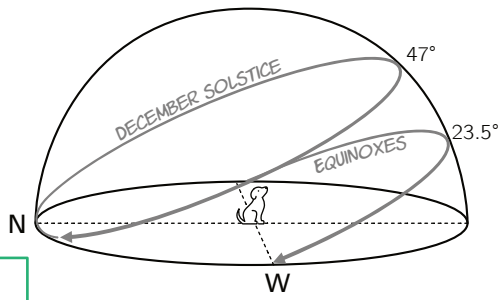


EQUATOR



TROPIC OF CANCER Because the position of the Sun at summer solstice is NORTH of the position of the Sun at winter solstice. The TROPIC OF CAPRICORN would look like this.





ANTARCTIC CIRCLE Because polar day is happening during the December solstice (which is the summer solstice for the southern hemisphere)

THE MOON: Earth's closest friend

Make a Model

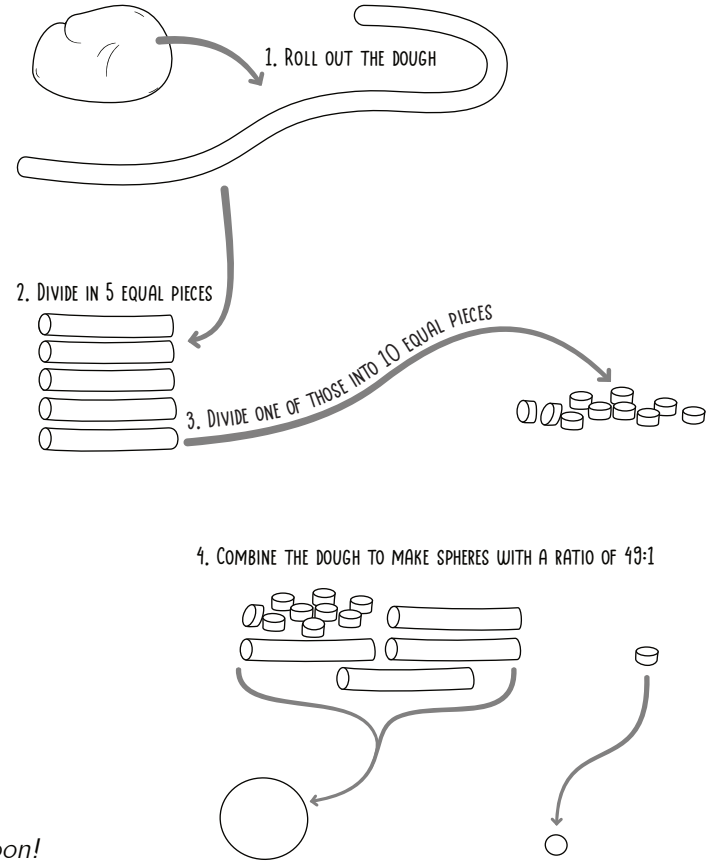
Earth and its moon are usually illustrated with their distance and size NOT to scale.

Here's a great modeling exercise to help you see how Earth and the Moon compare in size and how far apart they are from each other.

The only supplies you need are some clay or dough. A ruler or a piece of string might also be handy for estimating distance.

1. Roll the dough into a cylinder and divide it into five equally-sized portions.
2. Then divide one of those pieces into 10 equal size pieces.
3. Remove one of the small portions and roll it into a sphere. This sphere represents the Moon.
4. Combine the rest of the dough and roll it into a sphere. This sphere represents the Earth.
5. Measure the diameter of the model Earth. You can use a ruler or string or just take a visual estimate. Then place the Moon 30 "Earth diameter-lengths" away from your model Earth.

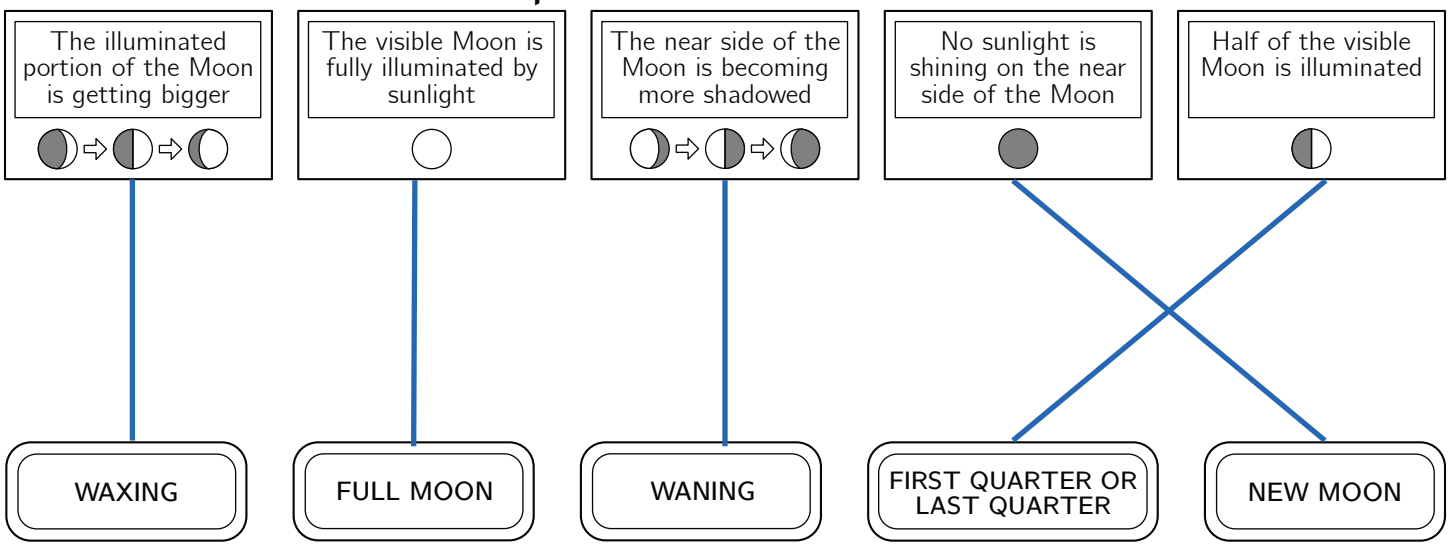
You now have a scaled model of the Earth and Moon!



Moons are natural satellites that orbit planets. Earth's moon, known simply as the Moon, is unusually large compared to the size of the Earth.

As it orbits Earth, different portions of its illuminated surface are visible from Earth; these are called the **phases of the Moon**. People have used them to measure the passage of time and other animals change or coordinate their activity based on the lunar cycle.

Draw a line to match each description with the correct term:



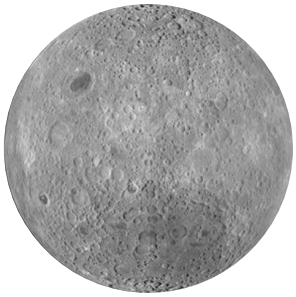
The Near & Far Sides of the Moon

The Moon is **tidally locked** with Earth, meaning that the same side is always facing Earth. The side of the Moon that we see from Earth has abundant craters, but there are also darker patches called **mare** (singular) or **maria** (plural). Formed by flood basalt, maria are lower in elevation than the lightly-colored lunar highlands.

What differences do you observe between the near side of the Moon (the side that faces Earth) and far side of the Moon? Does the Moon rotate? Why or why not?

NEAR SIDE

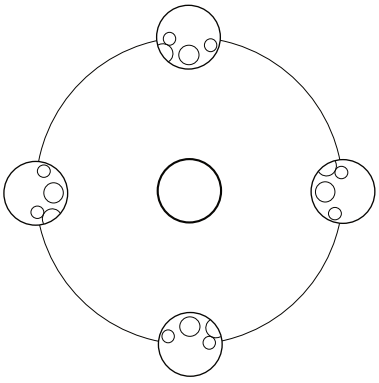
THERE ARE MORE MARIA ON THE NEAR SIDE OF THE MOON AND THEY ARE LARGER. THE FAR SIDE HAS VERY FEW MARIA BECAUSE IT HAS A THICKER CRUST.



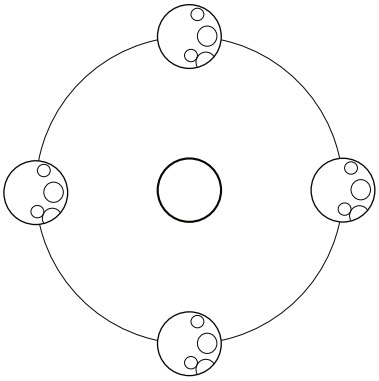
FAR SIDE

THE MOON ROTATES! IF IT DIDN'T ROTATE THEN WE WOULD SEE BOTH THE NEAR AND FAR SIDE. IT'S ROTATION PERIOD MATCHES THE LENGTH OF ITS ORBIT AROUND EARTH.

Image credits: NASA's Lunar Reconnaissance Orbiter/GSFC/Arizona State University



Tidally locked moon: the same side always faces the planet.



NOT tidally locked: the planet sees different sides of the moon.

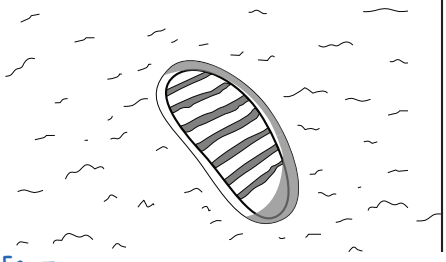
Fact or Fiction?

Consider each statement, then write whether it is fact or fiction.

The Moon is a dwarf planet that came too close and was captured by Earth's gravity

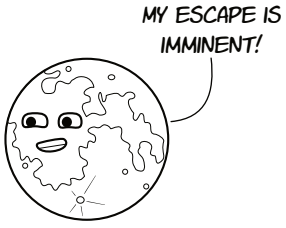
FICTION THE GIANT IMPACT HYPOTHESIS IS THE LEADING THEORY. IT SAYS A MARS-SIZED PLANET CRASHED INTO EARTH AND THE RESULTING DEBRIS COALESCED INTO THE MOON

Only 12 people have stepped on the Moon's surface. Their footprints are still visible today.



FACT AS OF 2025, 12 PEOPLE HAVE VISITED THE MOON. THEY WERE ALL FROM THE APOLLO MISSIONS (1961 TO 1972). ARTEMIS IS SCHEDULED TO TAKE PEOPLE TO THE MOON AGAIN IN 2028. EARTH-BASED TELESCOPES DON'T HAVE HIGH ENOUGH RESOLUTION TO SEE THE FOOTPRINTS, BUT MULTIPLE SATELLITES AROUND THE MOON HAVE TAKEN PHOTOS OF THE PRINTS.

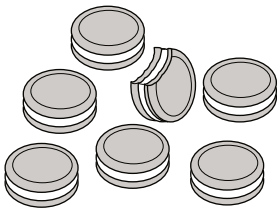
The Moon is drifting away from Earth at a rate of about 4 meters per year



FICTION THE MOON IS MOVING AWAY BUT NOT AT 4 M PER YEAR. THE RATE IS 4 CM PER YEAR.

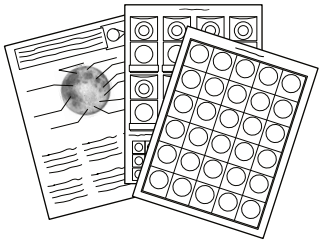
Cookie Models and Journal

MATERIALS

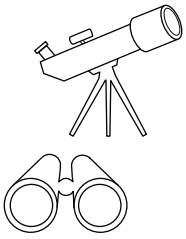


Sandwich style cookies with cream filling and a butter knife (optional)

Pencil, pen, or coloring supplies



Observe the Moon Page, Cookie Moon Phases Page, & Moon Journal Page,



Binoculars or telescope (optional)

GOALS

- Become more familiar with the Moon and its phases.
- Practice observing natural phenomena and keeping a detailed record of observations.

Complete the following 3 activities:

1. Observe the Moon & Label Famous Craters and Maria

You can observe the Moon during any of it's phases, but craters will be more visible when the Moon is NOT in the full moon phase. The more pronounced shadows of a crescent or quarter moon make it easier to see craters. Observe the Moon without any tools or equipment (naked eye), with binoculars, or with a telescope.

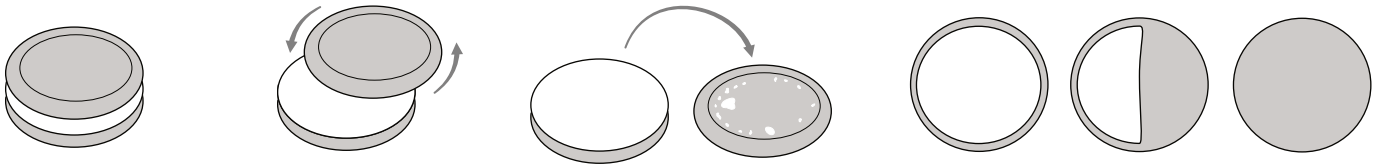
If you are unable to observe the Moon directly, you can explore virtually at https://science.nasa.gov/moon/

Use the descriptions of the craters and maria and online resources such as NASA to label the features on the **Observe the Moon** page. Then check the boxes next to each feature you're able to observe on the actual Moon.

Note: you may need to observe the Moon multiple times at different phases to be able to observe all 10 features.

2. Moon Phase Models

Fill out the chart on the **Cookie Moon Phases** page and check to be sure it's completed correctly. Then get 4 sandwich-style cookies. Carefully twist off the tops of each cookie. Use a butter knife to adjust the cream filling so that the cookie halves match the 8 phases of the moon. Once the cookies are complete, pick one at random. Can you place the remaining 7 phases in order? Complete this 3 times, with 3 different cookies as starting points. Bonus points if you can arrange the cookies in the correct order and name the phases without using the chart as a guide.



3. Observe moon for 30 days and draw/record phases

Observe the Moon daily for one month. Using the **Moon Journal Page**, record the date and the Moon's appearance by shading the portion that is shadowed or dark. If you are unable to observe the Moon due to clouds or other factors, write "no" (no observation) or "no data" in the circle.

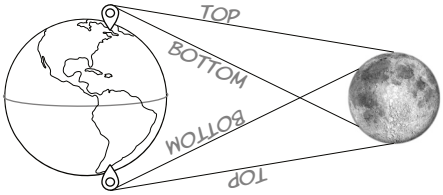
Did you observe the same phases during the 30 day time period?

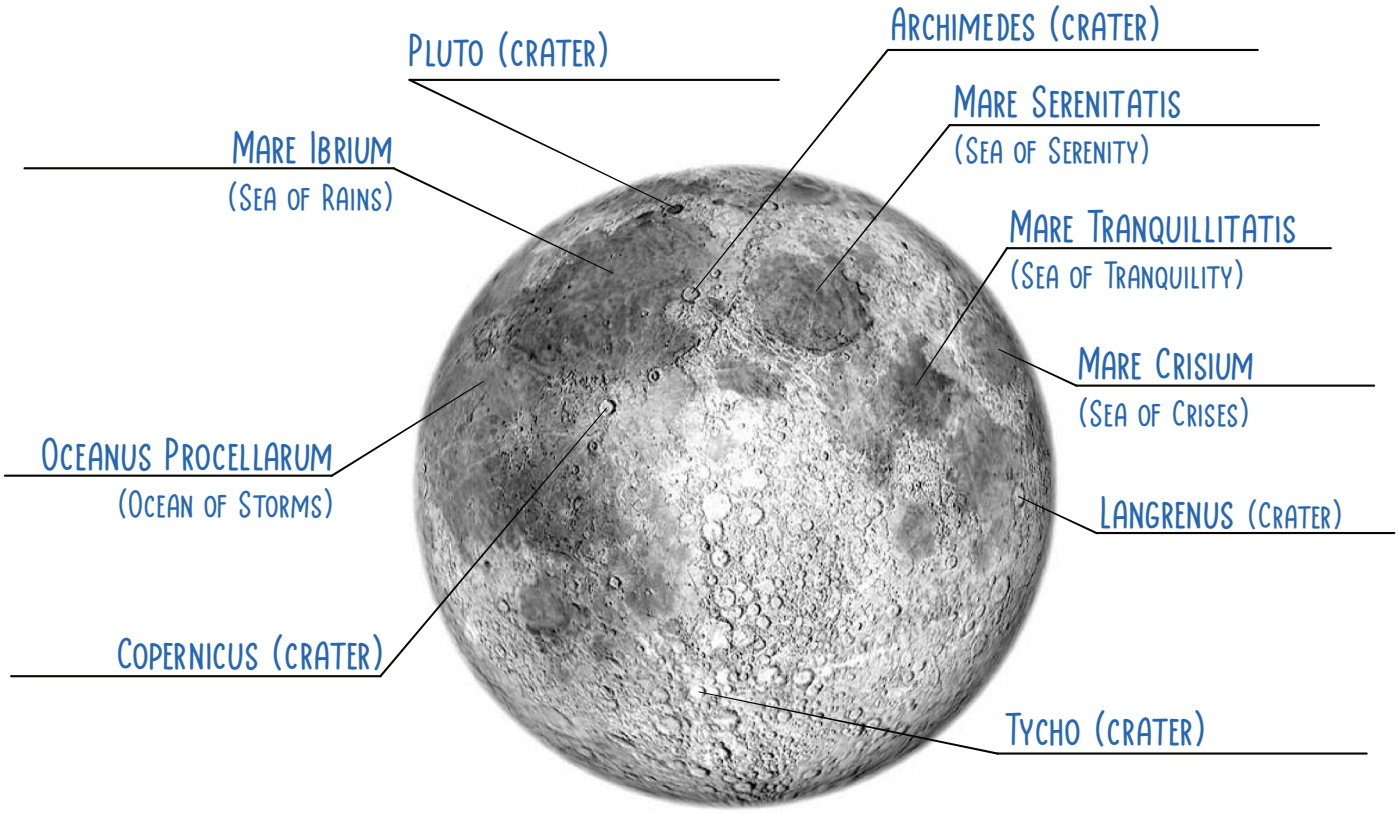
Did you observe any differences in when and where you could see the Moon during this month?

Observe the Moon (and Label Famous Craters and Maria too!)

The Moon's orientation depends on where we observe it!

*When viewed from the **Northern Hemisphere**, the Moon most often looks like the image below where the large maria are on "top" relative to the horizon. When viewed from the **Southern Hemisphere**, the orientation is reversed.*





CRATERS Place a checkmark by each crater you are able to observe on the Moon:

☐ **Archimedes** - In September of 1959 the Soviet probe Luna 2 crashed near this crater. It was the first craft to reach the Moon.
Diameter: 82 km

☐ **Copernicus** - This crater has rays that extend for more than 850 km and overlap other craters. It also has several peaks in the center
Diameter: 93 km

☐ **Langrenus** - This crater is on the eastern side of Mare Fecunditatis (south of Mare Crisium). It's central peak is about 3 km tall.
Diameter: 130 km

☐ **Plato** - This lava-filled impact crater has a floor that is darker than the surrounding terrain and lacks a central peak.
Diameter: 101 km

☐ **Tycho** - This distinctive bright white crater is surrounded by rays that extend outward in all directions. Some are over 1,500 km long!
Diameter: 85 km

MARIA Place a checkmark by each maria you are able to observe on the Moon:

☐ **Mare Crisium** - This is one of the smaller lunar maria, being about the same size as as the country of Uruguay.
Diameter: 556 km

☐ **Mare Imbrium** - This mare formed when lava flooded a giant crater. It's surrounded by mountains, more than 5 km tall.
Diameter: 1,145 km

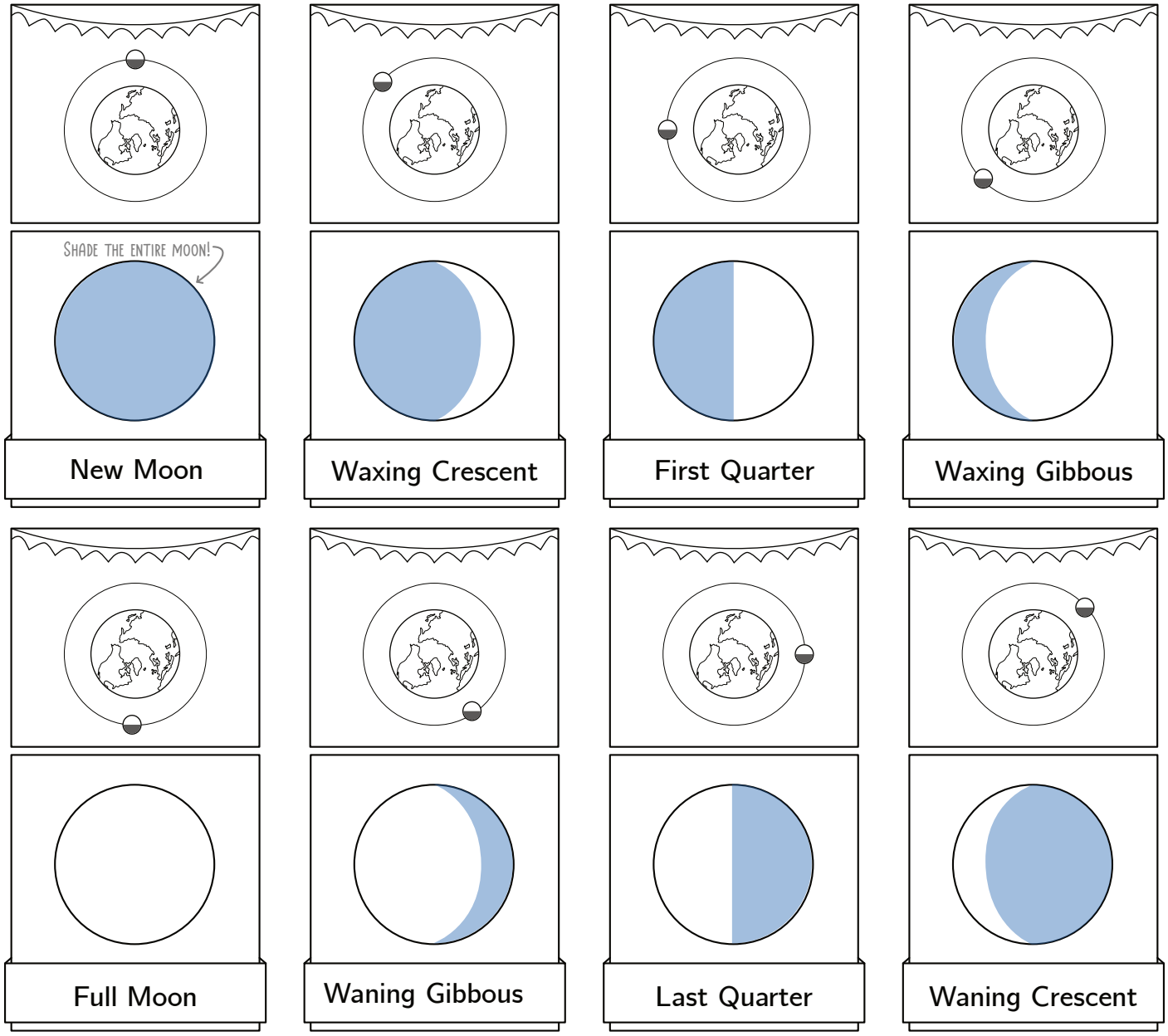
☐ **Mare Serenitatis** - This mare has a distinct circular shape. It has been visited by multiple lunar landers, including Luna 21 and Apollo 17.
Diameter: 674 km

☐ **Mare Tranquillitatis** - The Apollo 11 spacecraft landed on the southwest shore of this mare in 1969. The site of the first Moon walk!
Diameter: 876 km

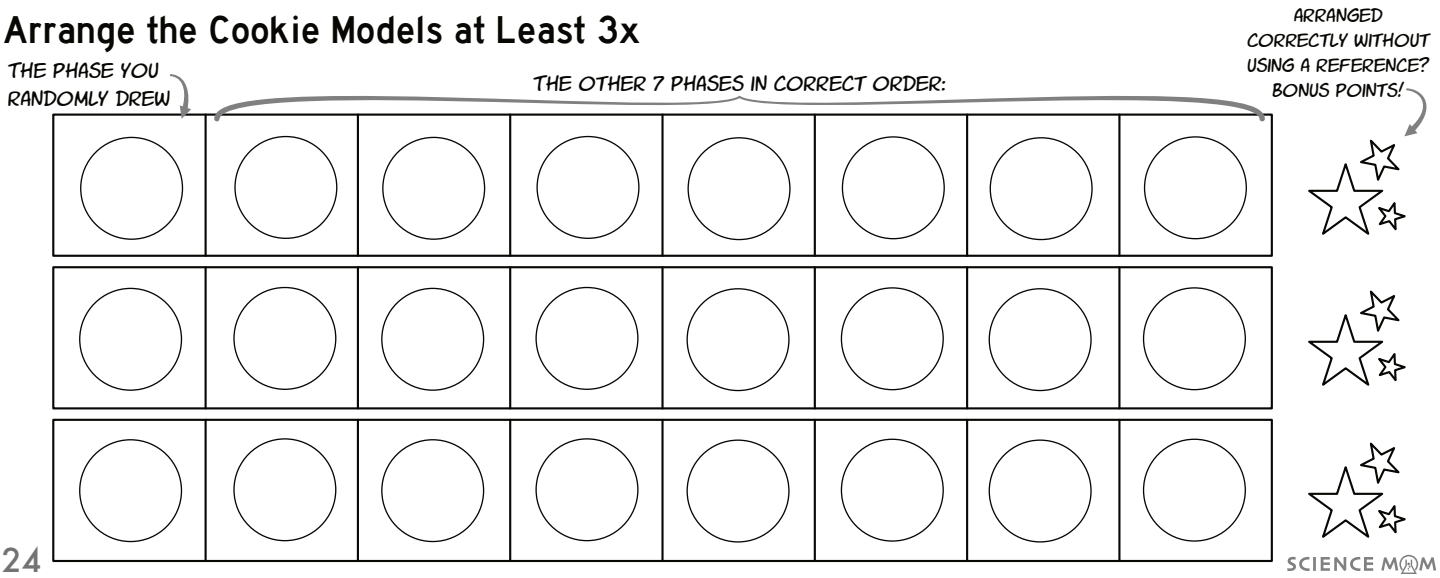
☐ **Oceanus Procellarum** - This mare is called "oceanus" due to its large size. It is not associated with a crater or impact event.
Diameter: 2,000 - 3,000 km

Cookie Moon Phases

For each phase below, color in the part of the Moon that is in shadow. Note: whether the bright portion of the waxing crescent is on the right or left hand side depends on whether you're in the Northern or Southern Hemisphere.



Arrange the Cookie Models at Least 3x



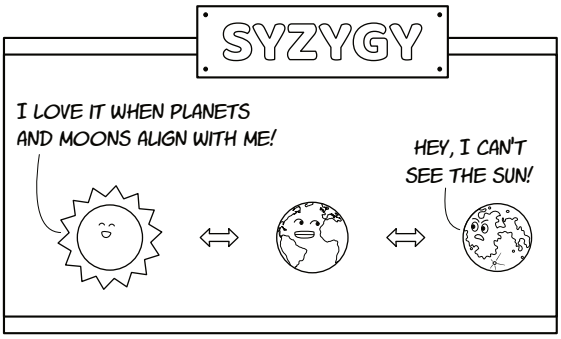
Moon Journal

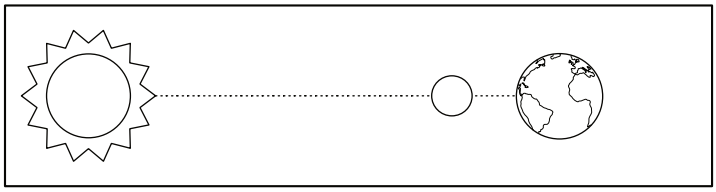
Date:	Date:	Date:	Date:	Date:
Date:	Date:	Date:	Date:	Date:
Date:	Date:	Date:	Date:	Date:
Date:	Date:	Date:	Date:	Date:
Date:	Date:	Date:	Date:	Date:
Date:	Date:	Date:	Date:	Date:

ECLIPSED

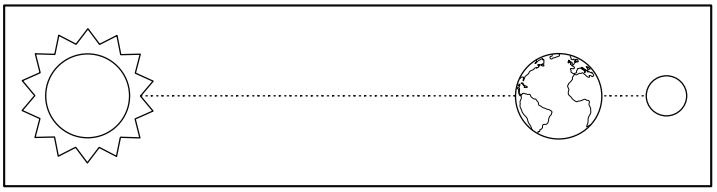
When 3 or more objects are arranged in a straight line, it's called **syzygy**. When an object that appears small (such as a distant planet) moves in front of an object that appears big (such as a large star) we call it a **transit**. If the objects are close enough that the shadow of one object covers another, it's called an **eclipse**.

Transits and eclipses are incredible events that help astronomers discover many new things, from the size of the Moon in 300 BCE to the discovery of new exoplanets today.

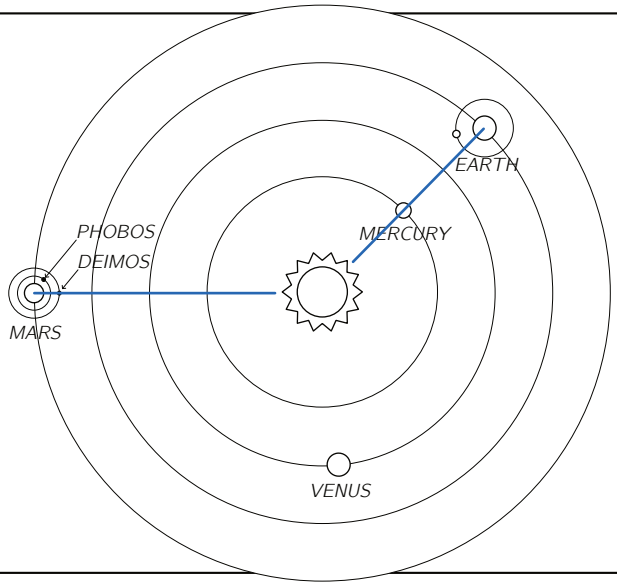




When the Moon passes between the Earth and Sun, it's a ___SOLAR___ eclipse.



When the Earth passes between the Sun and Moon, it's a ___LUNAR___ eclipse.

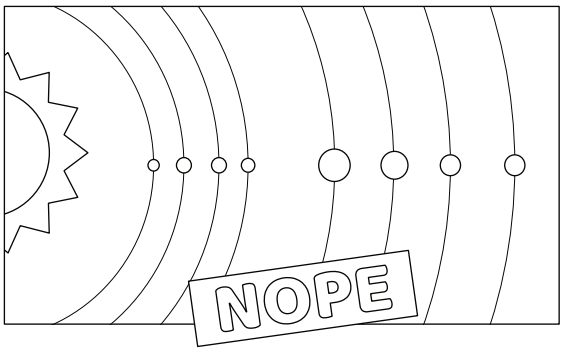


Which planets or moons are in syzygy with the Sun?

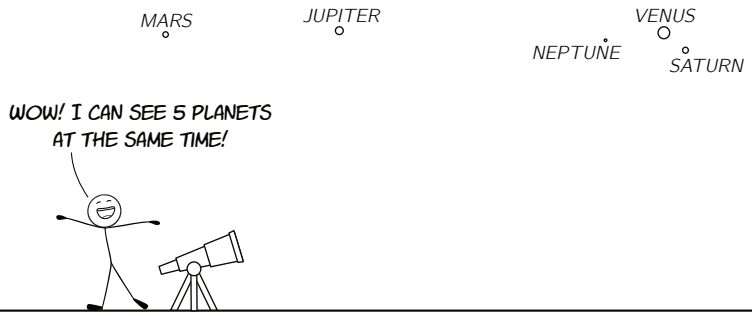
MERCURY AND EARTH ARE IN SYZYGY. TRANSITS OF MERCURY HAPPEN AROUND 10 TIMES IN A CENTURY. THE NEXT ONE WILL BE IN NOVEMBER OF 2032. VENUS TRANSITS ARE RARER, HAPPENING ABOUT ONCE A CENTURY. THE NEXT ONE WONT BE TILL 2117.

MARS AND DEIMOS ARE IN SYZYGY. FROM THE RIGHT LOCATION ON THE SURFACE OF MARS, THE MOON PHOBOS IS LARGE ENOUGH TO PRODUCE AN ANNULAR ECLIPSE (IT DOESN'T COMPLETELY COVER THE SUN, BUT BLOCKS MUCH OF THE LIGHT). DEIMOS IS TOO SMALL TO CAUSE AN ECLIPSE. WHEN IT IS IN SYZYGY SOMEONE ON MARS COULD OBSERVE IT TRANSIT THE SUN (IF THEY HAD THE RIGHT SOLAR FILTERS AND GEAR).

All 8 planets won't ever line up perfectly, but sometimes multiple planets are visible in the same area of the night sky.



When two or more planets come close together in the sky it's called a conjunction. When multiple planets are visible it might also be called a "parade of planets" or a large alignment.



Discoveries Due to Eclipses

Jupiter has 4 moons large enough to cause solar eclipses. When their orbits take them between the Sun and Jupiter, they cast distinct shadows that can be viewed from Earth. How did observing the eclipses of Jupiter's moons inspire the first calculation of the speed of light?

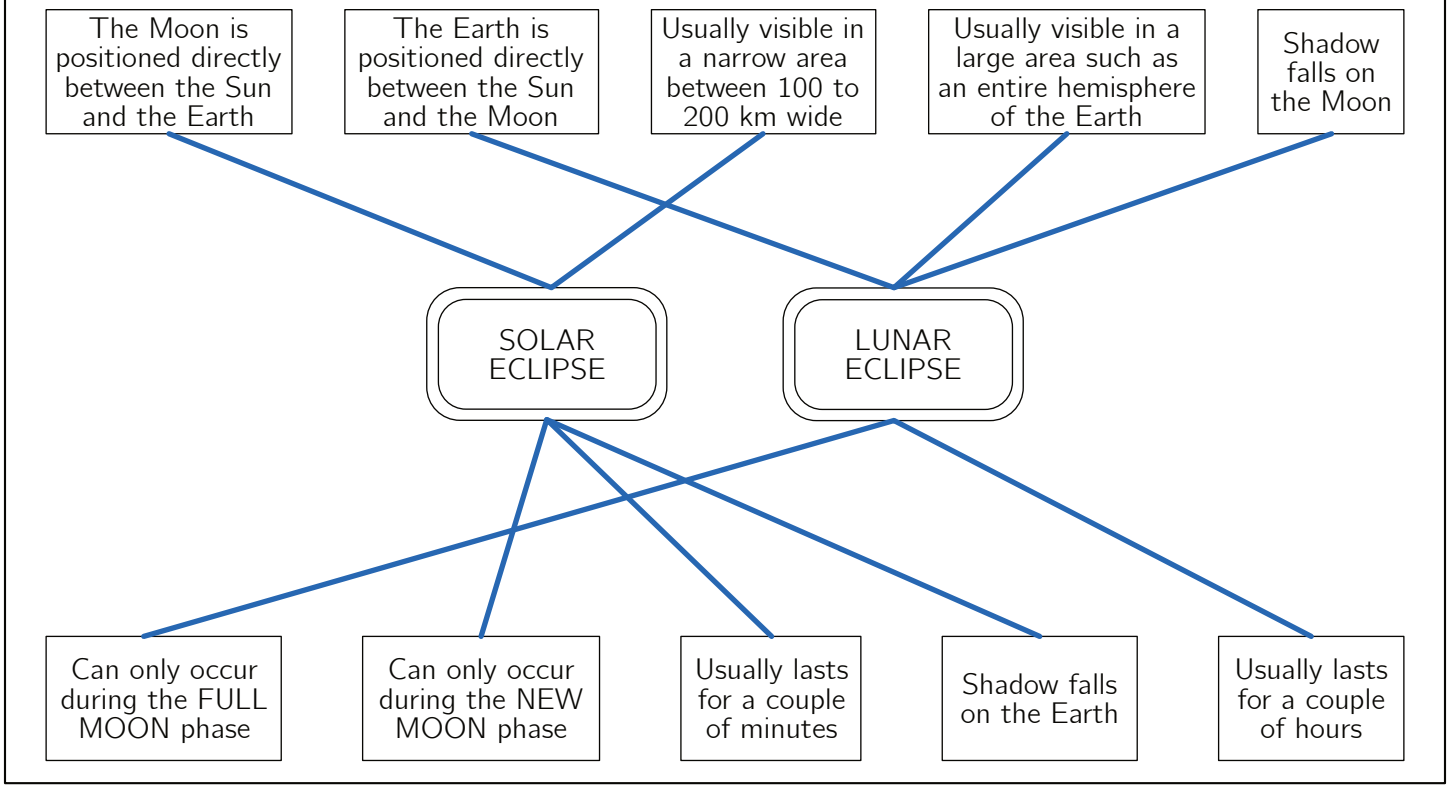
First calculation of the speed of light:

In 1676, Danish astronomer Ole Rømer measured that an eclipse occurred 11 minutes late when Jupiter was furthest from Earth. This showed Light takes to time to travel. Rømer estimated a speed of 211,000 km/s (Actual speed is 300,000 km/s)

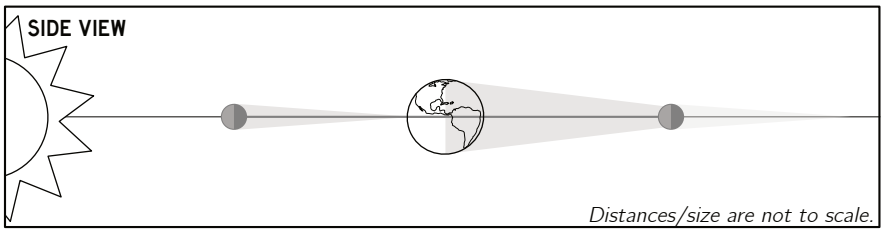
What other discoveries came from observing eclipses?

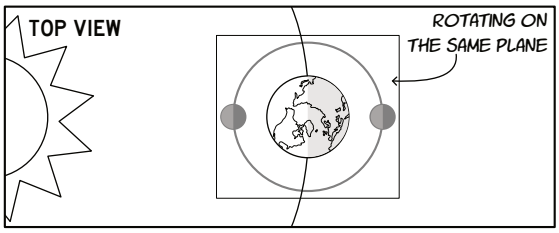
Discovery of Helium, general relativity confirmed, exoplanet detection, size of Moon and Sun and distance to the Moon and Sun calculated, Learn more about Earth's atmospheric composition and the Sun's corona.

Solar eclipse or lunar eclipse? Draw lines to match each description with the best fit.



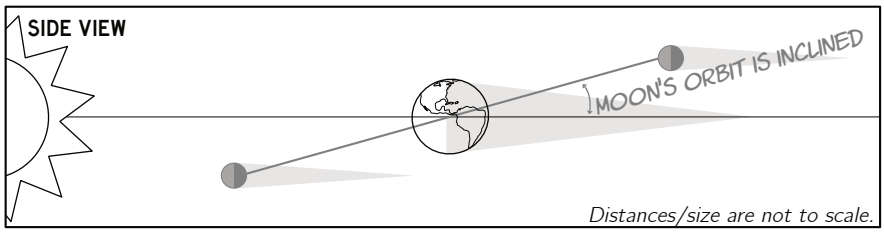
TOTALITY: a closer look at solar & lunar eclipses

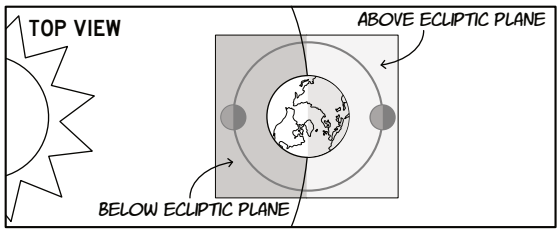




If the Moon, Earth, and Sun were all on the exact same plane, when would we see solar and lunar eclipses?

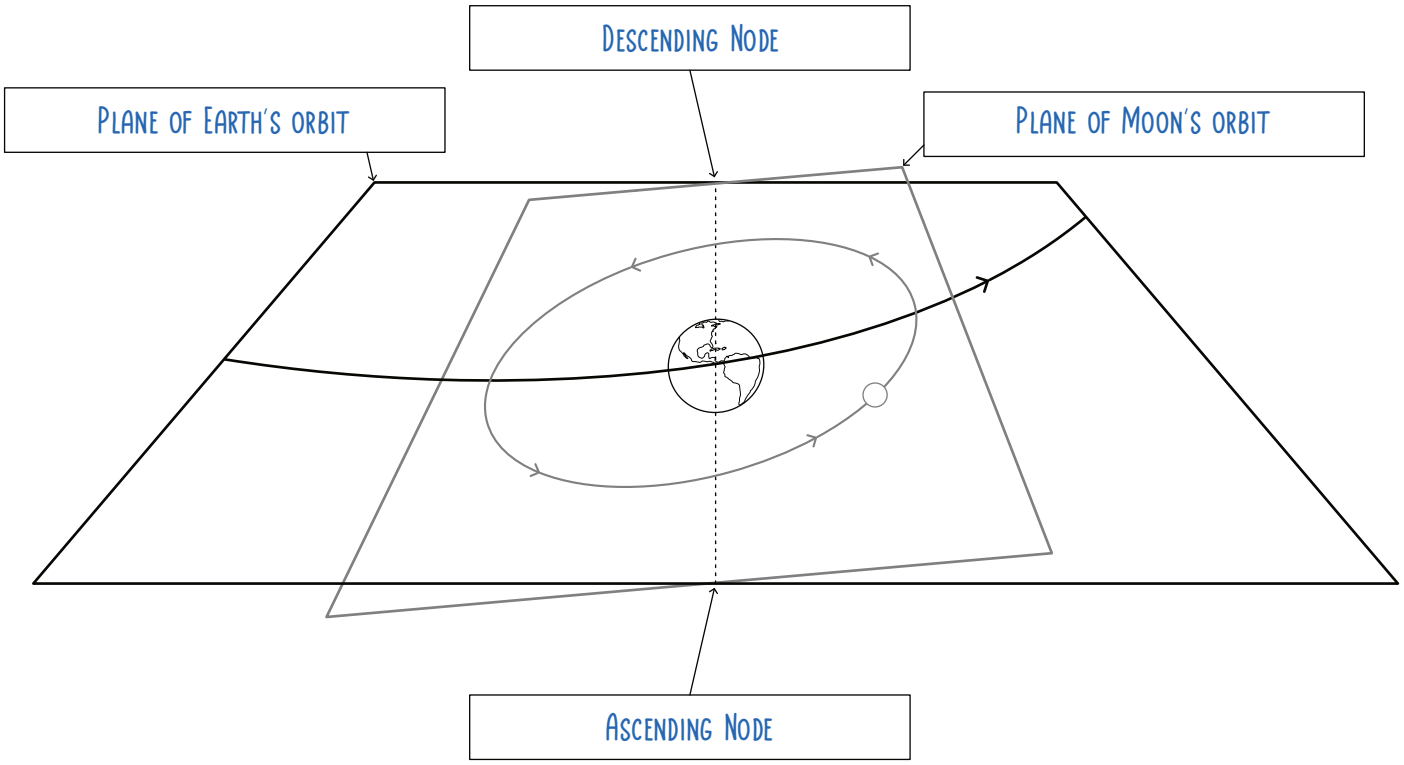
IF THERE WAS NO INCLINATION TO THE MOON'S ORBIT, THEN WE WOULD SEE SOLAR ECLIPSES WITH EVERY NEW MOON AND LUNAR ECLIPSES WITH EVERY FULL MOON.





If the Moon, Earth, and Sun were NOT on the same plane, when would we see solar and lunar eclipses?

AN ECLIPSE CAN ONLY HAPPEN WHEN THE MOON CROSSES THE ECLIPTIC PLANE. THIS OCCURS TWICE EACH LUNAR ORBIT, BUT TO PRODUCE AN ECLIPSE, THE CROSSING HAS TO COINCIDE WITH EITHER A NEW OR FULL MOON.



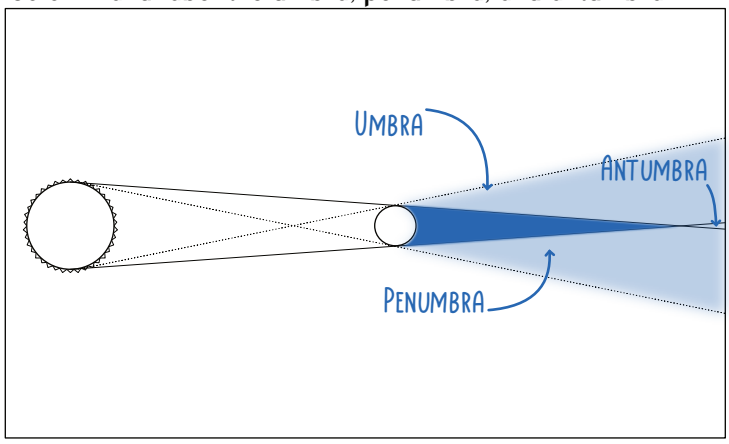
When sunlight shines on an opaque object, it casts a shadow. Most shadows have 3 parts:

Umbra: The dark inner part of a shadow. When viewed from the umbra, the Sun is completely blocked or obscured.

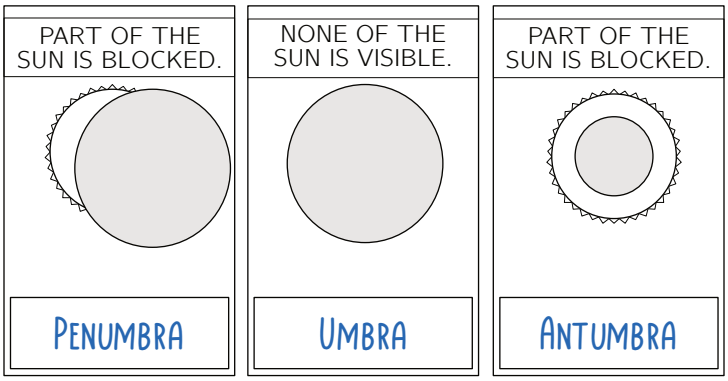
Penumbra: The lighter edge of a shadow. If the Sun is viewed from the penumbra, only part of it is blocked or obscured.

Antumbra: Not visible with short shadows. In the antumbra, the object making the shadow appears to be entirely within the Sun.

Color in and label the umbra, penumbra, and antumbra:



Where is the Sun being observed from? The umbra, penumbra, or antumbra?



Fact or Fiction?

Consider each statement, then write whether it is fact or fiction.

During a total lunar eclipse, the Moon appears red in color

Fact - due to sunlight scattering through Earth's atmosphere, a phenomenon known as "Rayleigh scattering."

Earth is the only planet in the solar system with a moon that causes total solar eclipses.

Fiction -Jupiter's large moons, like Io, Europa, and Ganymede, frequently cast shadows on the planet.

Every 12,000 years, a solar eclipse and a lunar eclipse will happen at the same time.

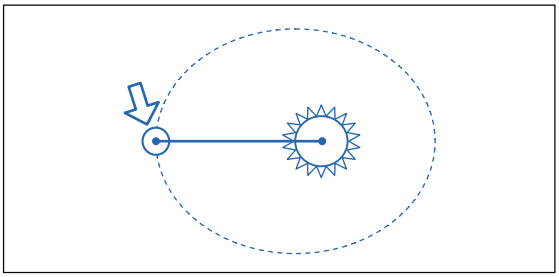
Fiction - The Earth and Moon will never cast shadows on each other simultaneously. Lunar eclipses can only happen at a full moon and solar eclipses occur during a new moon.

Earth & Moon Review

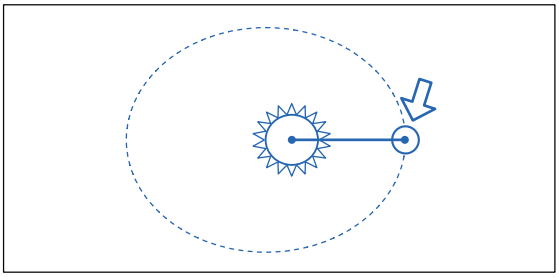
IN YOUR OWN WORDS!

Learning and understanding new words is an important part of astronomy! Define each of the following terms in your own words. Use the space in the box to draw and label a diagram.

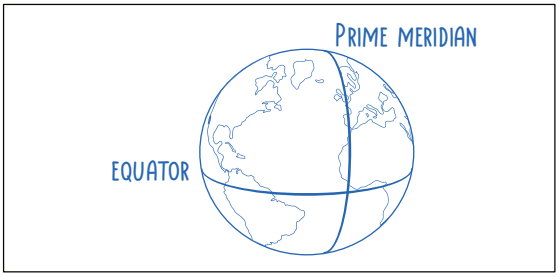
APHELION: The point in an orbit when an object is farthest from the Sun



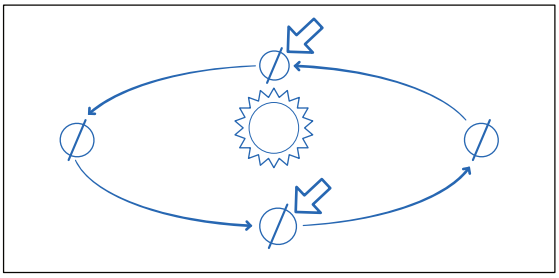
PERIHELION: The point in an orbit when an object is closest to the Sun



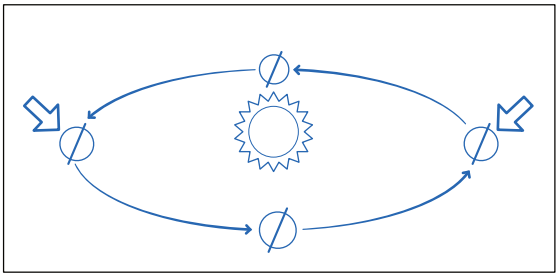
EQUATOR and PRIME MERIDIAN: Equator = the midpoint between the N and S poles. 0°north/south. Prime meridian = the longitude line that runs through Greenwich England. 0° east/west.



EQUINOX: The time of year when Earth's axis is perpendicular to the Sun's rays. Also the time of year when the Sun is directly overhead from the equator. Length of day and night is almost equal.



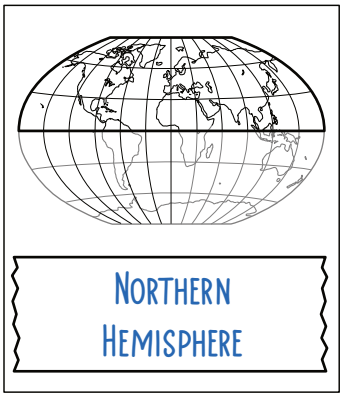
SOLSTICE: The time of year when Earth poles are most extremely tilted or inclined from the Sun. Also when the Sun is furthest north or south relative to Earth's equator.

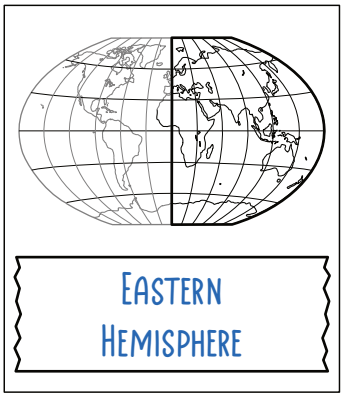


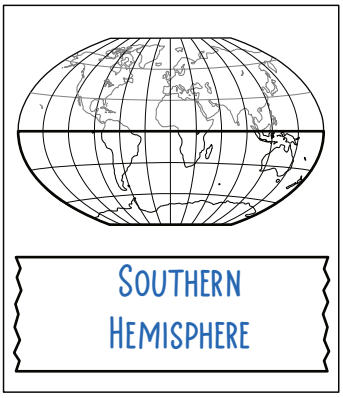
MATCH THE WORD WITH THE CORRECT DEFINITION

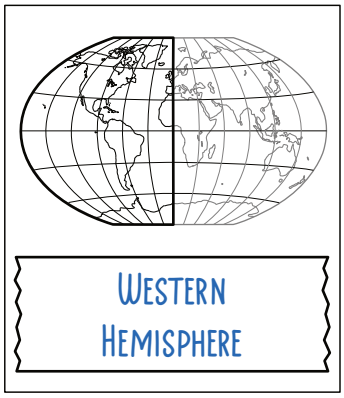
ECLIPTIC	The Sun's apparent path across the sky; the plane that contains both the Sun and Earth's orbit
LATITUDE	The angle between the direction of gravity and the plane of the Earth's equator; measures the distance north or south of the equator
LONGITUDE	Measures the east-west position of a point on Earth's surface
ORBIT	A repeating path that one object in space takes around another object, usually following an elliptical shape
REVOLVE	To move in a circular path around an object; to orbit around something
ROTATE	To spin or move around an axis or center
SYZYGY	When three or more objects are in a straight line
ZENITH	The highest point

LABEL THE HEMISPHERES









Earth & Moon Review

1. What is true about **astronomy**? (mark all that apply)
   - A. It is considered to be one of the branches of modern science
   - B. It is used to produce daily horoscopes
   - C. It relies heavily on mathematics and physics
   - D. It is used to study the physical properties of stars and planets

2. What is true about **astrology**? (mark all that apply)
   - A. It has lore and traditions surrounding the constellations that lie along the ecliptic
   - B. It relies heavily on mathematics and physics
   - C. It is considered to be one of the branches of modern science
   - D. It is used to produce daily horoscopes

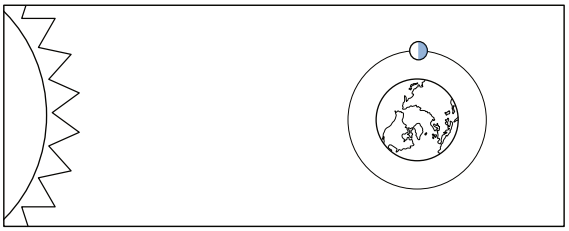
3. If a star sets during the night, in which direction will it fall below the horizon?
   - A. North
   - B. East
   - C. South
   - D. West

4. If the Sun is observed daily from the *Tropic of Capricorn*, in which direction does it most often reach its highest point or zenith?
   - A. North
   - B. East
   - C. South
   - D. West

5. What is the reason Earth has seasonal variations in daylight and temperature? In other words, what is the primary cause of spring, summer, autumn and winter?
   - A. Earth has an elliptical orbit
   - B. Earth rotates on a tilted axis
   - C. The Moon causes changes as it orbits
   - D. The Sun varies in brightness over the course of a year

6. The Sun is observed from a location north of the Tropic of Cancer. In which direction (relative to the viewer) will it reach its highest point in the sky?
   - A. North
   - B. South
   - C. Directly overhead (at the zenith)

7. Which of the following statements about the Moon are true?
   - A. It rotates faster than the Earth
   - B. On average, the far side of the Moon receives as much sunlight as the near side
   - C. The darker patches on the face of the Moon have higher elevation than the lighter patches
   - D. The moon does not rotate



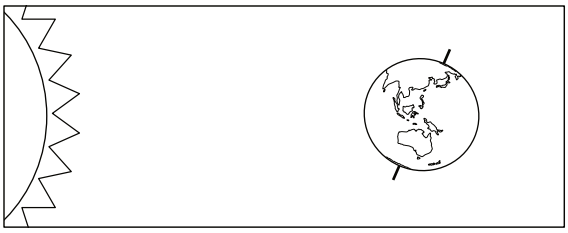
8. What phase of the Moon is visible if the Sun, Moon, and Earth are positioned as pictured above?
   - A. Full moon
   - B. Crescent or gibbous
   - C. Quarter
   - D. New moon

9. The Moon goes through a complete cycle of its phases approximately:
   - A. Daily
   - B. Weekly
   - C. Monthly
   - D. Yearly

10. A **lunar eclipse** can only occur during which Moon phase?
    - A. New moon
    - B. Crescent moon
    - C. Quarter moon
    - D. Full moon

11. What is the term for the line of latitude at 23.5° North?
    - A. Arctic Circle
    - B. Antarctic Circle
    - C. Tropic of Cancer
    - D. Tropic of Capricorn

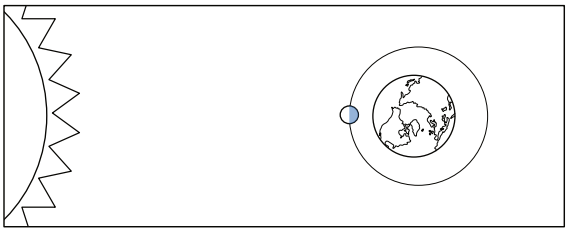
12. When is the autumn equinox in the *Southern Hemisphere*?
    - A. December
    - B. March
    - C. September
    - D. June



13. In the illustration above, is the Southern Hemisphere experiencing winter or summer?
    A. Winter
    B. Summer
    C. Neither

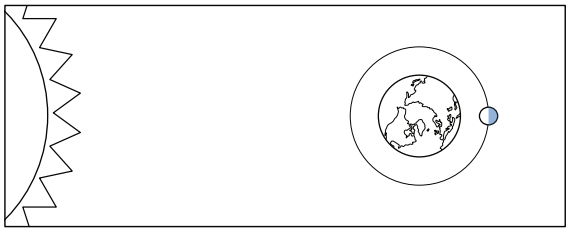
14. A **solar eclipse** can only occur at what phase of the Moon?
    A. New moon
    B. First quarter
    C. Full moon
    D. Last quarter

15. The dark areas on the Moon's surface are best described as:
    A. Craters
    B. Lava plains
    C. Mountains
    D. Oceans

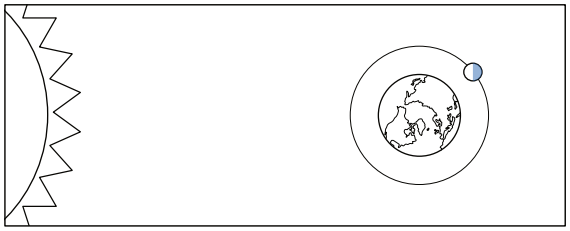


16. What phase of the Moon is visible if the Sun, Moon, and Earth are positioned as pictured above?
    A. Full moon
    B. Crescent or gibbous
    C. Quarter
    D. New moon

17. What is the name for the lighter outer part of a shadow?
    A. Umbra
    B. Penumbra
    C. Antumbra



18. What phase of the Moon is visible if the Sun, Moon, and Earth are positioned as pictured above?
    A. Full moon
    B. Crescent or gibbous
    C. Quarter
    D. New moon



19. What phase of the Moon is visible if the Sun, Moon, and Earth are positioned as pictured above?
    A. Crescent
    B. Full moon
    C. Gibbous
    D. Quarter

20. The gnomon on a sundial is:
    A. The curved part where the time is marked
    B. The shadow-casting bar or post
    C. The compass used to align the sundial
    D. The base of the sundial

LABEL EACH DESCRIPTION WITH THE CORRECT TYPE OF ECLIPSE (Annular, partial, or total and either lunar or solar)

The type of eclipse that occurs when the Moon is too far from Earth to completely cover the Sun, leaving a "ring of fire."

ANNULAR SOLAR ECLIPSE

Also called a "Blood Moon," this eclipse occurs when the Earth moves directly between the Sun and the Moon.

TOTAL LUNAR ECLIPSE

This type of eclipse produces crescent-shaped shadows on the ground.

PARTIAL SOLAR ECLIPSE

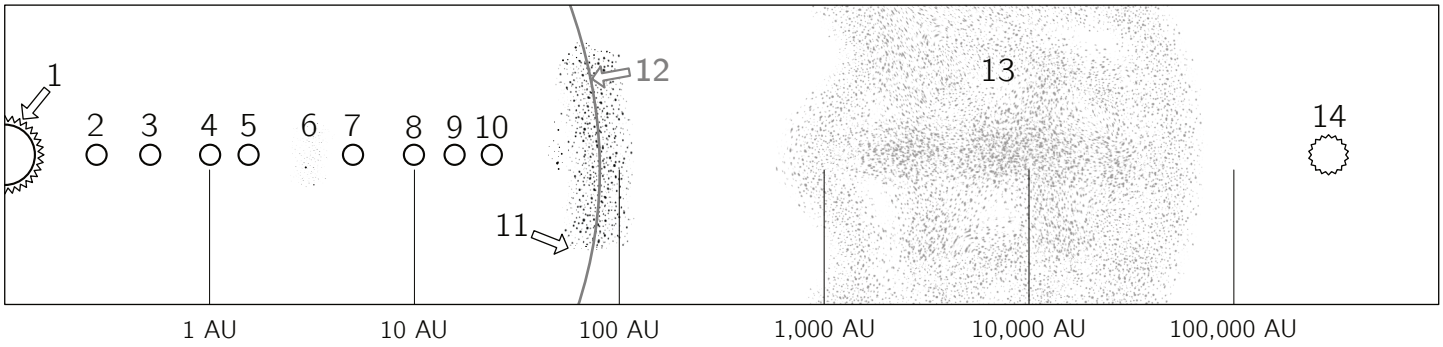
Our Solar System: scope and story

Fill in the blanks (words may be used more than once)

planets	Sun	dwarf	asteroids	comets	moons

Our solar system includes the SUN and all of the objects that orbit around it. In addition to 8 PLANETS, there are also 5 DWARF PLANETS, hundreds of MOONS, and over 1 million ASTEROIDS and COMETS. The SUN contains more than 99% of the total mass of the solar system.

A logarithmic scale diagram of our solar system (and it's closest neighbor)



Each distance is the number of astronomical units from the Sun.

Label and briefly describe the features in the diagram above:

1 OUR SUN (NAMED SOL) - CENTER OF THE SOLAR SYSTEM

2 MERCURY - A ROCKY PLANET

3 VENUS - A ROCKY PLANET

4 EARTH - A ROCKY PLANET

5 MARS - A ROCKY PLANET

6 THE ASTEROID BELT - MATERIAL THAT COULD HAVE FORMED A PLANET IF JUPITER'S GRAVITY HADN'T INTERFERED

7 JUPITER - A GAS GIANT

8 SATURN - A GAS GIANT

9 URANUS - AN ICE GIANT

10 NEPTUNE - AN ICE GIANT

11 THE KUIPER BELT - PRONOUNCED "KY-PER" CONTAINS ICY ASTEROIDS, COMETS, AND DWARF PLANETS (PLUTO, ERIS ETC)

12 EDGE OF THE HELIOSPHERE - THE REGION WHERE THE SOLAR WIND HAS A SIGNIFICANT INFLUENCE

13 THE OORT CLOUD - A BUBBLE-SHAPED REGION OF ICY MATERIALS, SOURCE OF COMETS

14 ALPHA CENTAURI - THE CLOSEST STAR TO OURS

In the logarithmic scale diagram, each distance is TEN TIMES further than the previous one. An Astronomical Units (AU) is the average distance from Earth to the Sun (150 million kilometers). Artwork is modeled after a diagram from NASA/JPL: https://photojournal.jpl.nasa.gov/catalog/PIA17046

Fact or Fiction?

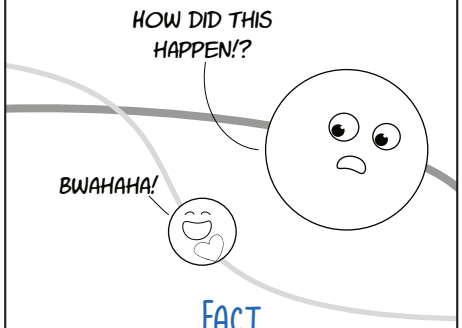
Consider each statement, then write whether it is fact or fiction.

Earth is the only place in the solar system with liquid water

Fiction

The moons Enceladus and Europa have liquid water oceans beneath ice. Ceres and Pluto may also have liquid water.

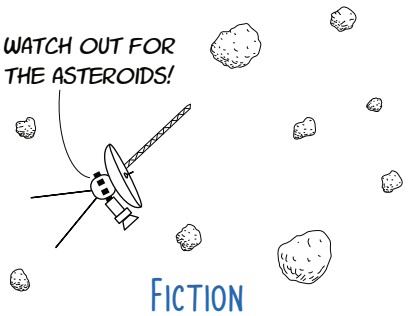
Neptune is sometimes further from the Sun than Pluto



Fact

Pluto has an irregular and tilted orbit that sometimes takes it inside of Neptune's orbit.

Spacecraft traveling through the asteroid belt are at high risk of collisions



Fiction

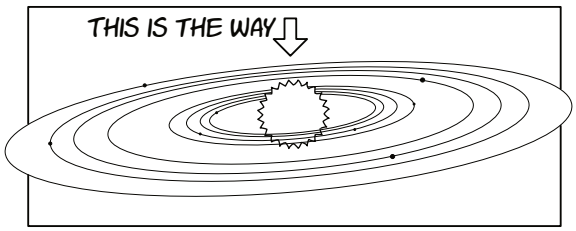
On average, asteroids in the belt are 1 million kilometers apart! It would be more challenging to collide with an asteroid than to miss them.

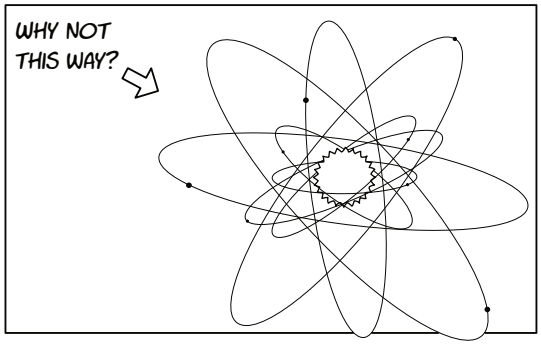
Why do the planets all rotate in the same plane?

Why not perpendicular to each other or random orientations? Consider and then write down a few of your thoughts.

Answers will vary. The goal of this question is to invite thinking and connections.

Students might note that spinning things tend to flatten out (tossing pizza dough, chair swing ride at an amusement park).

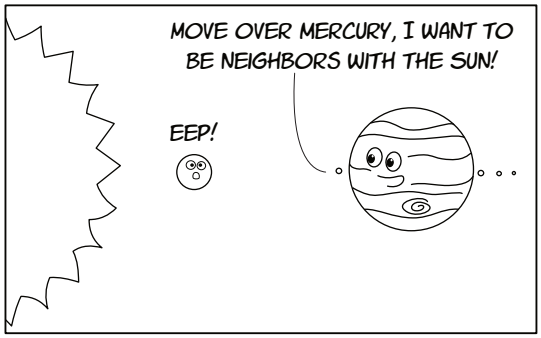




Why rocky, then gassy, then icy?

Why aren't the planets arranged from largest to smallest or in some other order instead? Consider and write a few ideas.

Answers will vary. The goal of this question is to invite thinking and connections.

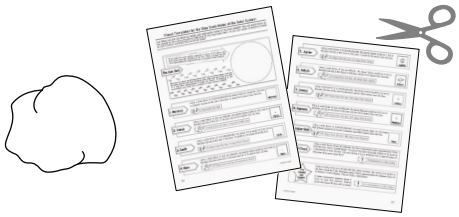


The order and shape of the planets has to do with how they were formed, something we'll learn more about when we talk about star formation! But the brief overview is that a nebula (cloud of dust and gas) collapses together and begins to spin. This forms a disk where bigger pieces collide with each other to form planets and a star. When the star begins fusion, the solar wind blows the remaining gas out of the solar system.

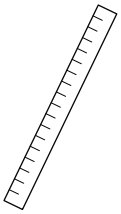
The Scale of the Solar System

MATERIALS

Chalk or something to mark a location



Modeling clay/dough for sculpting OR the printable planet templates from the appendix and scissors



A yardstick or tape measure (optional)

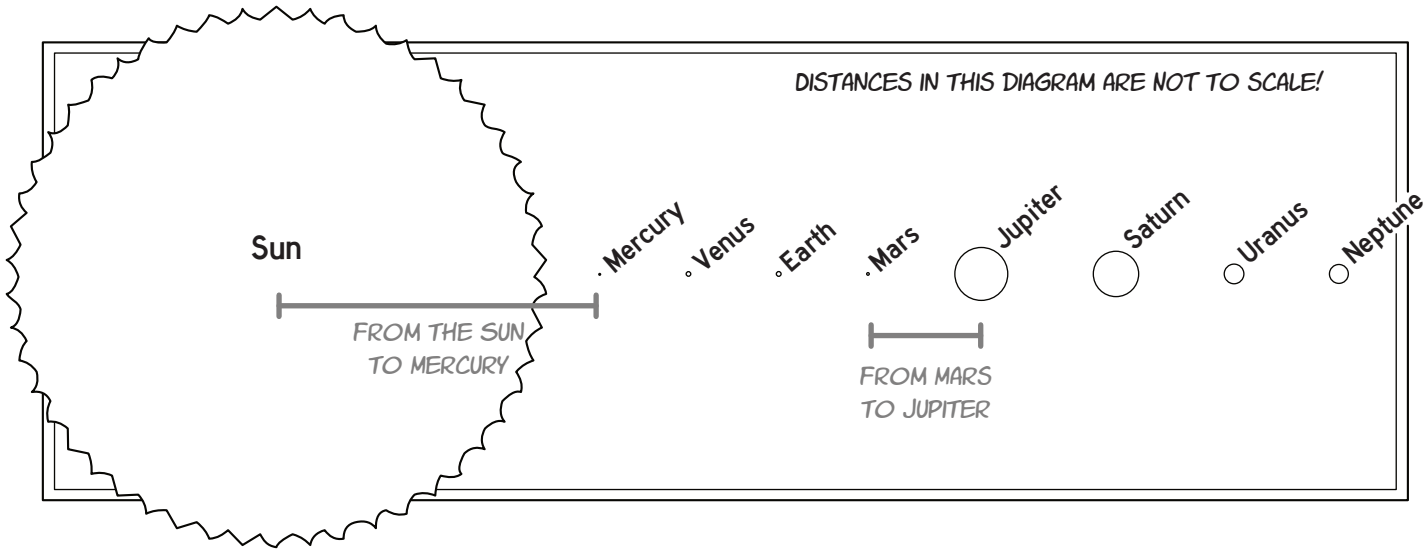
GOALS

- Create a scale model of the planets.
- Create a scale model of the solar system distances.

In most of the pictures or diagrams of the solar system, the planets and distances are not to scale. In this activity we'll build a scale model of the planets and the distances between them using a scale factor of one to ten billion.

If we apply that scale to the objects in the solar system, the Sun and 8 planets look like this:

The Sun and Planets (at a scale factor of 1/10,000,000,000)



The distances above are not accurate for the size of the Sun and planets. **But what if they were?** If the Sun had a diameter of 70 mm (that's about as wide as a dollar bill in US currency), then how far would Mercury be from the Sun? What about Jupiter from Mars? Take a guess!

Your guess or estimate:

1. From the Sun to Mercury: _____

2. From Mars to Jupiter: _____

Now that you've made your guesses, it's time to make a scaled model and find out the answer!

Walking the Solar System

1. Make models of the objects in our solar system either by cutting out the printable scaled planets in the appendix OR by making them with clay or dough (note: if using clay, the inner planets will be almost too small to pick up! You could place them on index cards for easier handling.)

2. Find a long straightaway on a non-busy street, sidewalk, or flat open area. Ideally, find a distance that is the length of two football fields or longer.

3. Choose a location on the ground for the Sun. Have a person stand there to mark the spot OR place the paper or clay/dough model of the Sun there OR mark the location with chalk.

4. Use the Step-Scale chart below to find the distance to Mercury in steps. Pace the distance or use a tape measure if you prefer to measure meters. (To convert steps to meters, just divide the number of steps by 2)

5. Continue the same process with the remaining planets. Take a picture or your solar system model when you get to significant milestones like Earth or Neptune.

Step-Scale Solar System Distances

	Distance from Sun	Distance from last planet
Sun	0 steps	0 steps
Mercury	6 steps	6 steps
Venus	11 steps	5 steps
Earth	15 steps	4 steps
Mars	23 steps	8 steps
Jupiter	78 steps	55 steps
Saturn	143 steps	65 steps
Uranus	287 steps	144 steps
Neptune	451 steps	164 steps
Pluto	591 steps	140 steps

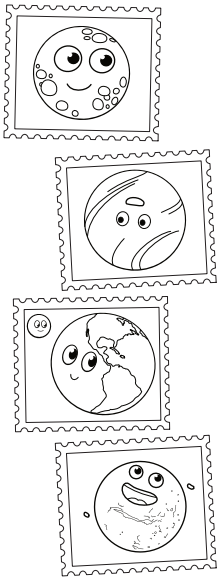
This chart assumes each step is half a meter in length.

What surprised you about this activity? Did you run into any challenges while doing it?

The Inner and Outer Planets

The inner planets are the 4 planets closest to the Sun: Mercury, Venus, Earth, and Mars. These planets are also are called ROCKY or TERRESTRIAL planets because they have solid surfaces. They each have iron cores, a high amount of silicate minerals in their crusts, and all of them have been volcanically active.

Fill in the chart below for the inner planets:

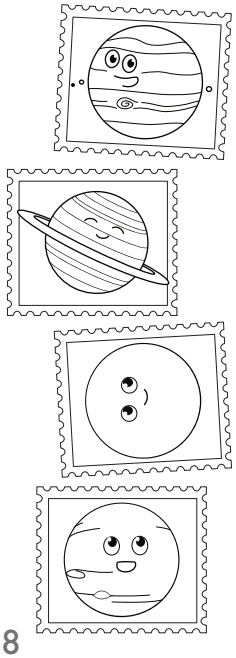


	Distance from the Sun AU	Solid surface Y or N	Number of moons	Atmosphere	Average surface temperature Celsius	Volcanism in present or past Y or N
Mercury	0.38	Y	0	No	333°C Most extreme temperature swing: -170 to 430°C	Yes
Venus	0.72	Y	0	Yes: Thick 96% CO_2 3% N_2	464°C	Yes
Earth	1	Y	1	Yes: Perfect 78% N_2 21% O_2	15°C	Yes
Mars	1.5	Y	2	Yes: Thin 95% CO_2 3% N_2	-65°C	Yes

The outer planets are the 4 planets furthest away from the Sun: Jupiter, Saturn, Uranus, and Neptune. These large planets have no solid surface. Their dense atmospheres get thicker and more dense until they become liquid. Deep within each giant outer planet is a solid core.

Jupiter and Saturn are called GAS GIANTS because apart from their solid core, they are almost entirely made of hydrogen and helium. Uranus and Neptune are called ICE GIANTS because they are mostly made of water, methane, and ammonia.

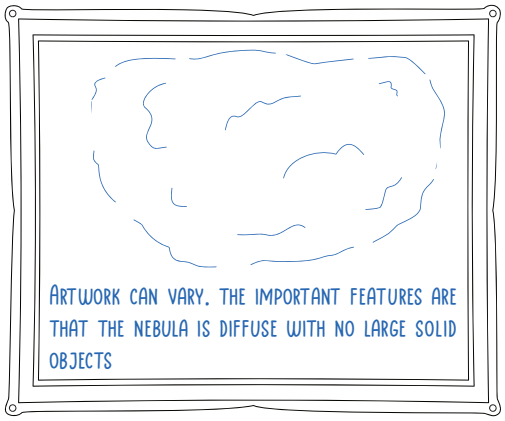
Fill in the chart below for the outer planets:



	Distance from the Sun AU	Solid surface Y or N	Number of moons	Most abundant elements outside of the small rocky core	Temperature at 1 atm of pressure in Celsius	Does the planet have rings? Y or N
Jupiter	5.2	N	95	Hydrogen Helium	-110°C	Yes
Saturn	9.6	N	146	Hydrogen Helium	-140°C	Yes
Uranus	19.2	N	28	Water Methane Ammonia	-195°C	Yes
Neptune	30.1	N	16	Water Methane Ammonia	-200°C	Yes

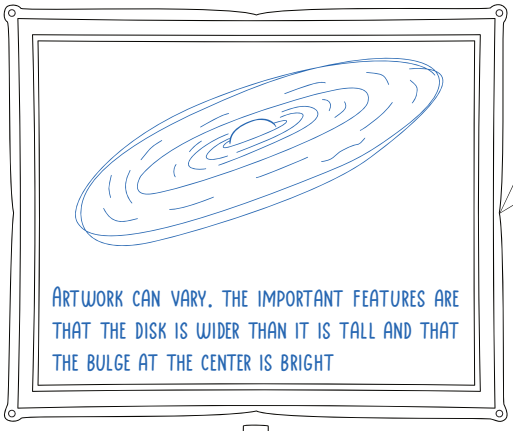
Draw pictures or diagrams in each frame to illustrate the formation of the solar system

1 A large **nebula** exists in space, made of hydrogen, dust, and some heavier elements. A distant supernova sends a shockwave through the cloud and the gas begins to collapse inward.



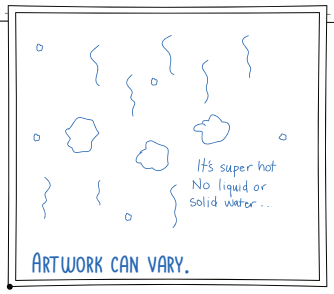
ARTWORK CAN VARY. THE IMPORTANT FEATURES ARE THAT THE NEBULA IS DIFFUSE WITH NO LARGE SOLID OBJECTS

2 The material in the nebula starts contracting and swirling around until it forms a **protoplanetary disk**. The material at the center of the disk is called a **protostar**. The protostar is growing in mass and very hot and bright, but it hasn't started fusion yet.

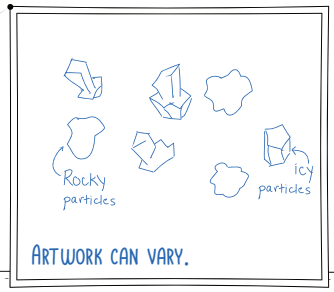


ARTWORK CAN VARY. THE IMPORTANT FEATURES ARE THAT THE DISK IS WIDER THAN IT IS TALL AND THAT THE BULGE AT THE CENTER IS BRIGHT

The inner region of the disk is very hot. Rocky materials are solid but materials like water, methane, and ammonia only exist as gasses. In this region, accretion only occurs with rocky materials. Small pieces combine to form larger bodies called planetesimals.



ARTWORK CAN VARY.

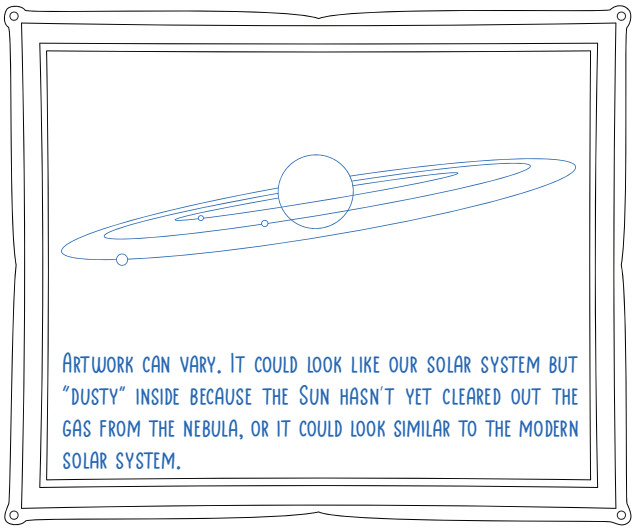


ARTWORK CAN VARY.

The outer region of the disk is cooler. Rocky materials are solid but so is water, methane, and ammonia. Here, accretion occurs with both rocky materials and frozen ices like water and methane.

3 When the protostar becomes large enough, pressure at its center is large enough that hydrogen atoms begin to fuse, forming helium. It's now a real star!

The solar wind produced by the star blows away the remaining gas and dust. The planets and moons are now clearly visible.



ARTWORK CAN VARY. IT COULD LOOK LIKE OUR SOLAR SYSTEM BUT "DUSTY" INSIDE BECAUSE THE SUN HASN'T YET CLEARED OUT THE GAS FROM THE NEBULA, OR IT COULD LOOK SIMILAR TO THE MODERN SOLAR SYSTEM.

Planetary Motion

Fill in the blanks

orbits Latin ecliptic direction elliptical appear retrograde

Viewed from a fixed point in outer space, the planets move around the Sun in predictable ORBITS. These paths aren't perfectly circular, they are ELLIPTICAL. Planets always travel in the same DIRECTION. Viewed from Earth, the planets usually appear to move east to west along the ECLIPTIC. But sometimes they APPEAR to move backwards. Ancient astronomers called this RETROGRADE motion. The word "retrograde" comes from the LATIN words retro (backward) and gradus (step).

How are a planet's speed (year length) related to the distance from the Sun?

A. Planets closer to the Sun orbit at the **same speed** as those further away

B. Planets closer to the Sun orbit **faster** than those further away

C. Planets closer to the Sun orbit **slower** than those further away

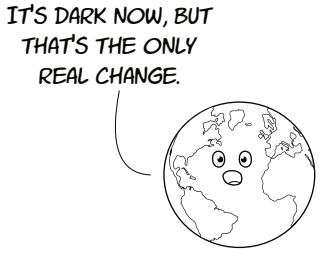
Why is this the case?

B IS CORRECT BECAUSE THE PULL OF GRAVITY BETWEEN THE SUN AND A PLANET IS STRONGER WHEN THE DISTANCE IS SHORTER. OBJECTS CLOSER TO THE SUN MUST BE MOVING FASTER IN A PERPENDICULAR DIRECTION TO MAINTAIN THEIR DISTANCE FROM THE SUN THAN OBJECTS THAT ARE FURTHER AWAY.

Fact or Fiction?

Consider each statement, then write whether it is fact or fiction.

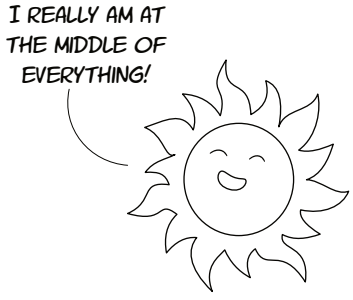
If the Sun disappeared, the planets would keep moving in their same orbits.



FICTION

THE PLANETS WOULD CONTINUE IN THE SAME SPEED AND DIRECTION AND FLY OFF INTO SPACE

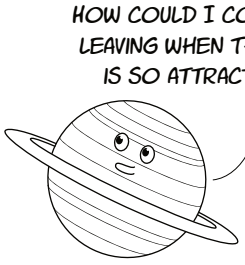
The Sun is at the exact center of each planet's orbit.



FICTION

THE SUN IS AT ONE OF THE FOCAL POINTS OF EACH PLANET'S ORBIT. IT'S NOT QUITE THE EXACT CENTER – IT'S JUST OFF CENTER

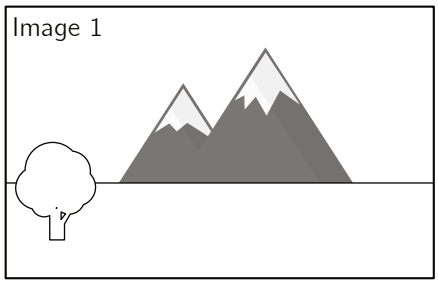
Gravity is the primary force keeping the planets in orbit around the Sun.

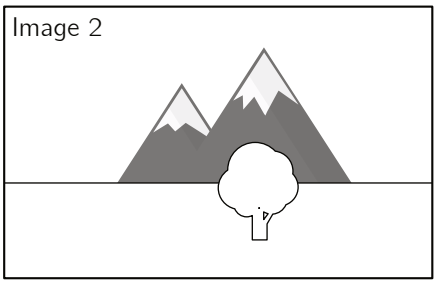


FACT

THE SUN IS THE MOST MASSIVE OBJECT IN THE SOLAR SYSTEM SO IT HAS THE STRONGEST GRAVITATIONAL PULL

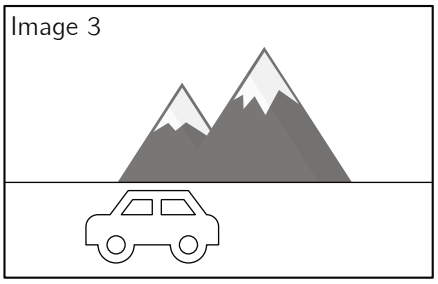
Parallax

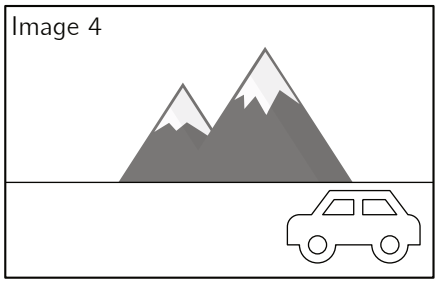




Bob looks out the car window and sees image 1. A few seconds later, he looks out the window and sees image 2. Is Bob traveling to the left or to the right? Explain.

Bob is traveling to the left. The tree and mountain aren't moving relative to each other, so Bob's vantage point must have moved to the left so that the tree and mountain line up.



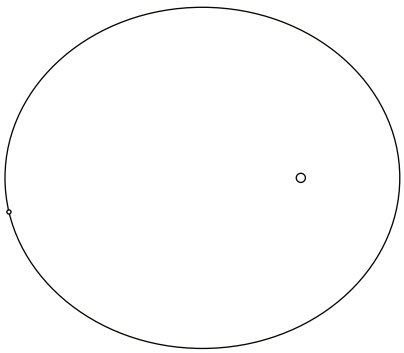


Bob looks out the car window and sees image 3. A few seconds later, he looks out the window and sees image 4. Is Bob traveling to the left or to the right? Explain.

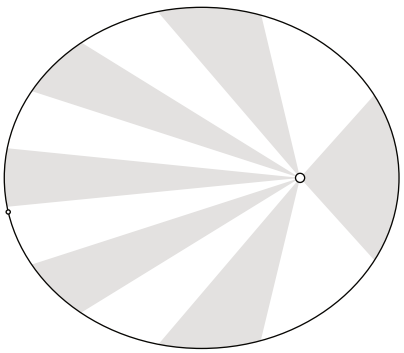
We need more information. Bob could be stationary while the car is traveling to the right. Bob could be going to the left at a faster rate than the other car. Bob could also be going to the right while the other care is traveling to the right even faster.

Kepler's Laws

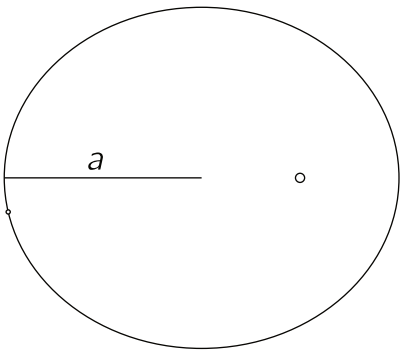
1. Planets move in elliptical orbits with the Sun as a focus.



2. A line that joins a planet to the Sun sweeps equal areas of space in equal time intervals.



3. A planet whose semi major axis has length a will complete a full orbit in $T = \sqrt{a^3}$ Earth years.
(a is measured in AU)

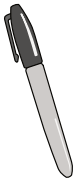


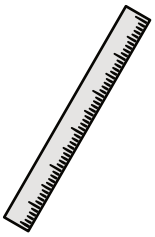
Ellipses and Orbits

MATERIALS


String


2 pins


Marker or pen


Ruler

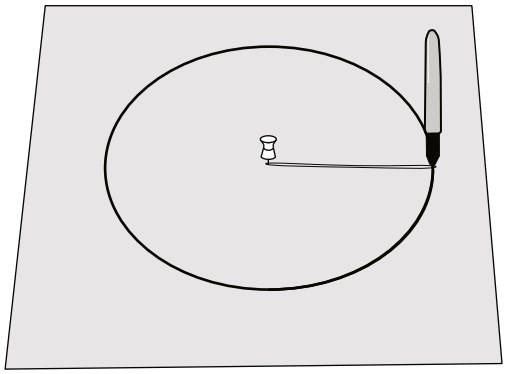

Flat piece(s) of cardboard

GOALS

- Construct elliptical orbits using geometry.
- Calculate the eccentricity of orbits.
- Calculate orbital periods.

Kepler's 1st Law states that planets follow an elliptical orbit with the Sun at a focus point of the ellipse. In this activity we'll learn how to construct an ellipse and what a focus point is.

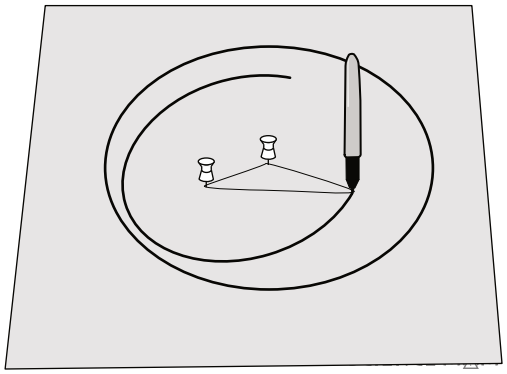
Constructing a Circle.



1. Cut about a foot of string, and tie a knot so that the string makes a big loop.
2. Place a dot near the center of the cardboard and label it "Sun".
3. Place a push pin into the center of the Sun. Place padding under the cardboard if needed.
4. Place the loop around the pin, and insert the pen into the loop as well. Pull the string taut as you draw a shape as far from the pin as the loop of string will allow.
5. The resulting shape is a circle, which has a mathematical definition of "the set of points in a plane that are all the same distance from a central point." The string keeps the distance constant.

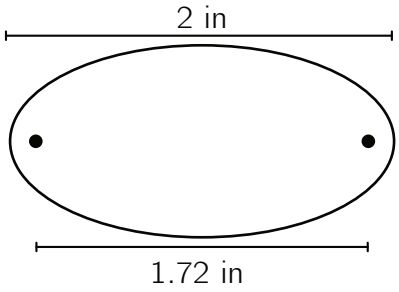
Constructing an Ellipse.

1. Now place a second pin into the cardboard. Each pin will be the focus of our ellipse.
2. You may reuse the string or make one of a different length.
3. Place the loop around both pins, and insert the pen into the loop as well. Pull the string taut as you draw a shape as far from the pins as the loop of string will allow.
4. The resulting shape is a ellipse, which has a mathematical definition of "the set of points in a plane that are the same total distance away from two points when you add the distances." Note that the length of string between the pins stays constant and doesn't play any role in the definition.
5. Keep the Sun in the same position, but move the other pin around and use loops of different lengths to create more ellipses.

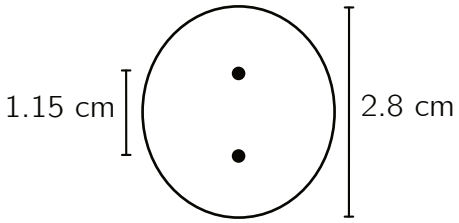


Eccentricity

A long, narrow ellipse is said be highly eccentric, while a circle has no eccentricity (or 0 eccentricity). To calculate the eccentricity, we divide the distance between the dots by the length of the major axis (the widest distance).



$$e = \frac{1.72}{2} = 0.86$$



$$e = \frac{1.15}{2.8} = 0.41$$

Find the eccentricity of each of your ellipses.

1. Measure the distance between the two focus points.
2. Divide it by the total width of the ellipse.

- Were any of your ellipses more eccentric than Mars? (e = 0.0934)
- Were any of your ellipses more eccentric than Pluto? (e = 0.25)
- Were any of your ellipses more eccentric than Halley's Comet? (e = 0.967)

Orbital Period

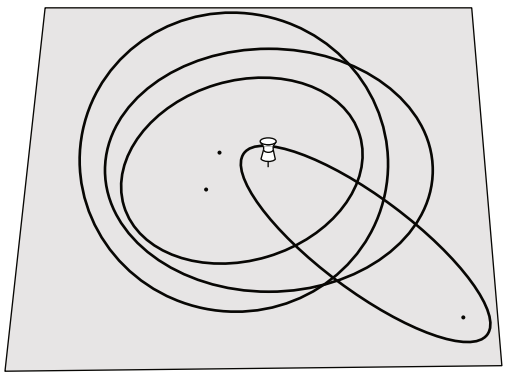
We can calculate the number of Earth years it takes for an object to complete a full orbit by measuring the semi major axis (half of the total widest distance) in AUs and then plugging that value a into the formula:

$$T = \sqrt{a^3}$$

Suppose the solar system whose orbits you designed is scaled so that 1 inch equals 1 AU. Find the orbital period for each planet or satellite in your solar system.

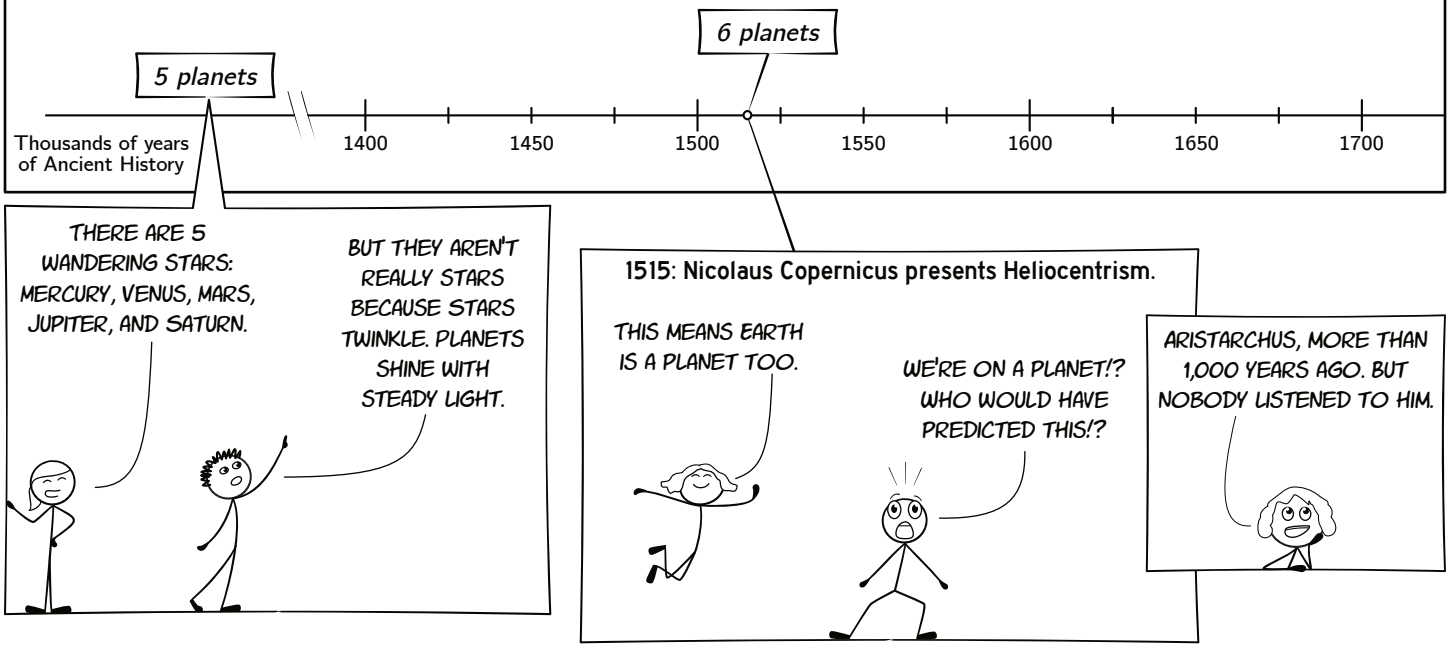
1. Measure the full width of each ellipse in inches and divide that number in half to get the length of the semi major axis.
2. Plug that value into the the formula $T = \sqrt{a^3}$ in place of a to get the number of Earth years, T. (A calculator will come in handy.)

- Which of your orbits has the longest transit time?
- Were you surprised by any of the results?

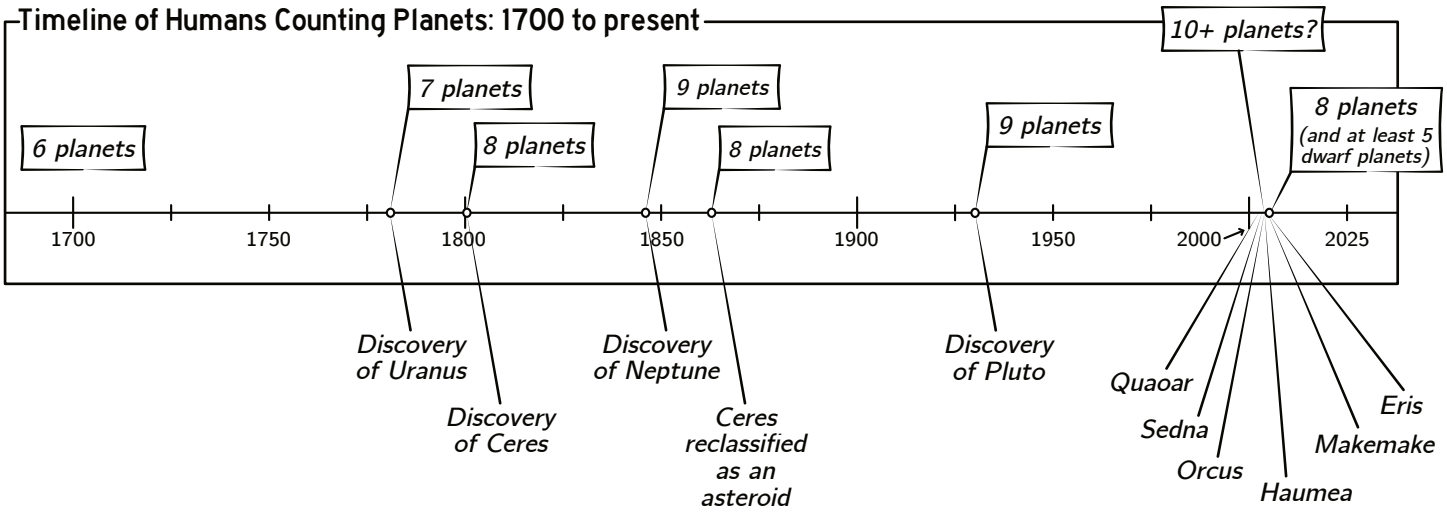


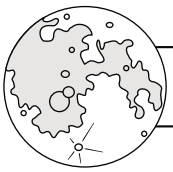
Dwarf Planets and Moons

Timeline of Humans Counting Planets: antiquity to 1700



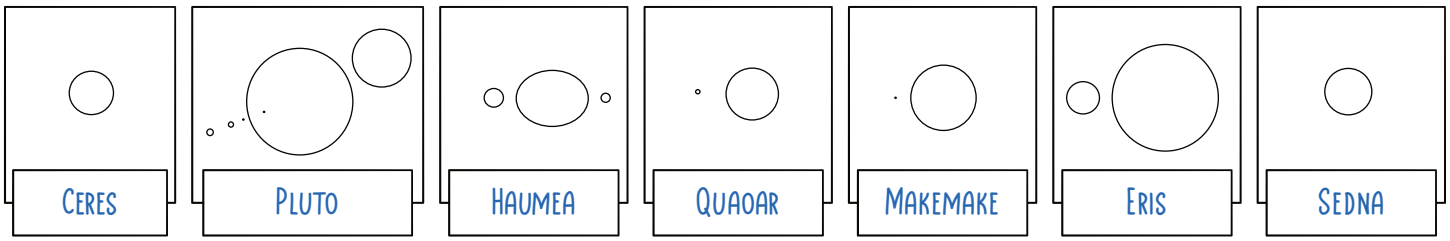
Timeline of Humans Counting Planets: 1700 to present





Fill in the name of each dwarf planet or Trans-Neptunian Object (TNO):

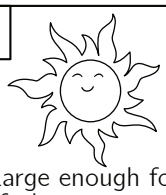
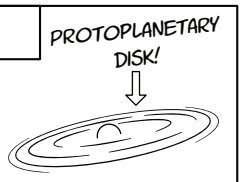
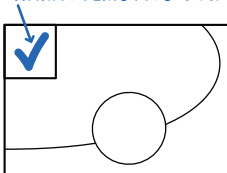
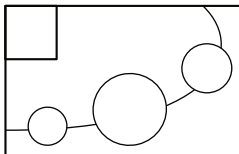
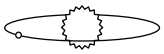
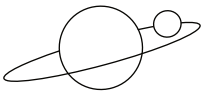
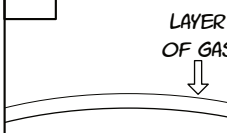
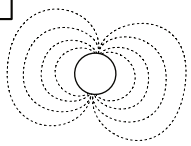
Earth's moon (diameter 4,567 km) is shown here at the same scale as the objects below



CERES	PLUTO	HAUMEA	QUAOAR	MAKEMAKE	ERIS	SEDNA
952 km diameter 2.8 AU from Sun No moons Discovered 1801	2,376 km diameter 39 AU from Sun 5 moons Discovered 1930	1,740 km diameter 43 AU from Sun 2 moons Discovered 2004	1,100 km diameter 43.7 AU from Sun 1 moon Discovered 2002	1,430 km diameter 45.8 AU from Sun 1 moon Discovered 2005	2,400 km diameter 68 AU from Sun 1 moon Discovered 2005	900 km diameter 83.55 AU from Sun No moons Discovered 2003

Characteristics of things in space:

CHARACTERISTICS FOR IAU DEFINITION OF PLANET

- ☐  Large enough for fusion to occur (80x the size of Jupiter)
- ☑  Becomes round under the force of its own gravity (diameter of ~600 km)
- ☐  Formed at the same time as a star
- ☑  Does NOT share orbit with similarly-sized objects
- ☐  Shares orbit with similarly-sized objects
- ☑  Travels in a regular path around a star
- ☐  Has at least 1 moon
- ☐  Has a core made of more dense material such as iron
- ☐  Has an atmosphere
- ☐  Has its own magnetic field

What is your opinion about the definition of a planet? Put a checkmark by each characteristic you think should be included from the boxes above. Then explain and defend your definition.

ANSWERS CAN VARY SO LONG AS YOU HAVE A SOLID JUSTIFICATION FOR YOUR DEFINITION! THE INTERNATIONAL ASTRONOMICAL UNION (IAU) DEFINES A PLANET AS BEING A CELESTIAL BODY THAT IS IN ORBIT AROUND A SUN, HAS ENOUGH MASS TO BE ROUND (HYDROSTATIC EQUILIBRIUM), AND HAS "CLEARED THE NEIGHBORHOOD" AROUND ITS ORBIT. PERSONALLY, I PREFER A BROADER DEFINITION BECAUSE PLANETS THAT GET EJECTED FROM A SOLAR SYSTEM (ROGUE PLANETS) ARE STILL PLANETS EVEN IF THEY NO LONGER ORBIT A STAR.

Moons to know in our solar system

The Galilean Moons of Jupiter

Io

- INNERMOST MOON OF JUPITER.
- SLIGHTLY LARGER THAN EARTH'S MOON. SUPER DENSE.
- HAS MOUNTAINS TALLER THAN EVEREST AND MORE THAN 400 ACTIVE VOLCANOES!
- CRUST AND MANTLE ARE HIGH IN SULFUR, GIVING IT BEAUTIFUL COLORS OF YELLOW, RED, WHITE, AND BLACK.

Europa

- SMALLEST GALILEAN MOON (SLIGHTLY SMALLER THAN EARTH'S MOON). HAS AN OCEAN OF LIQUID WATER UNDERNEATH IT'S CRUST OF FROZEN WATER.
- HAS THE SMOOTHEST SURFACE OF ANY OBJECT IN THE SOLAR SYSTEM.

Ganymede

- LARGEST MOON IN SOLAR SYSTEM (3/4 THE SIZE OF MARS!)
- THE ONLY MOON WITH ITS OWN MAGNETIC FIELD BUT IT DOESN'T HAVE MUCH OF AN ATMOSPHERE.
- IT'S INTERNAL OCEAN HAS LIQUID WATER.

Callisto

- 3RD LARGEST MOON IN SOLAR SYSTEM. MOST HEAVILY CRATERED OF ANY OBJECT IN SOLAR SYSTEM!
- MIGHT HAVE LIQUID WATER UNDERNEATH ITS THICK AND ICY SURFACE.

2 moons of Saturn

Titan

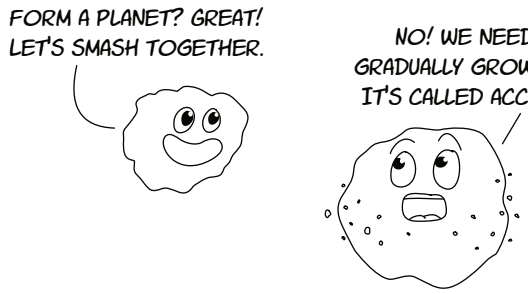
- 2ND LARGEST MOON IN SOLAR SYSTEM (LARGER THAN MERCURY). ONLY MOON WITH AN ATMOSPHERE DENSER THAN EARTH'S ATMOSPHERE (IT'S MOSTLY NITROGEN AND METHANE).
- IN OUR SOLAR SYSTEM, TITAN IS THE ONLY OBJECT BESIDES EARTH TO HAVE RAIN, LAKES, AND RIVERS. BUT TITAN'S RAIN IS MADE OF HYDROCARBONS! IT'S SO COLD ON TITAN THAT METHANE CONDENSES. ALL THE WATER ON TITAN IS FROZEN.

Enceladus

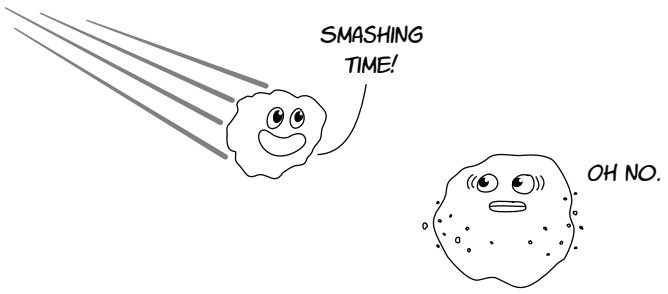
- THIS SMALL MOON IS SUPER BRIGHT. IT'S ONE OF THE MOST REFLECTIVE BODIES IN THE SOLAR SYSTEM.
- WATER ERUPTS CONTINUOUSLY FROM THE SURFACE. SOME OF IT LEAVES ENCELADUS AND CONTRIBUTES TO SATURN'S E-RING. BUT MOST FREEZES AND FALLS BACK TO THE MOON'S SURFACE AS SNOW.
- ITS OCEAN OF LIQUID WATER IS ONE OF THE MOST LIKELY PLACES TO FIND LIFE OUTSIDE OF EARTH.

Asteroids, Comets, and Meteors

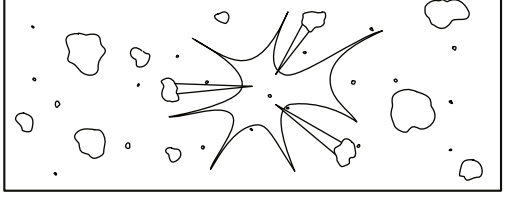
Billions of years ago, a group of planetesimals considered becoming a planet.



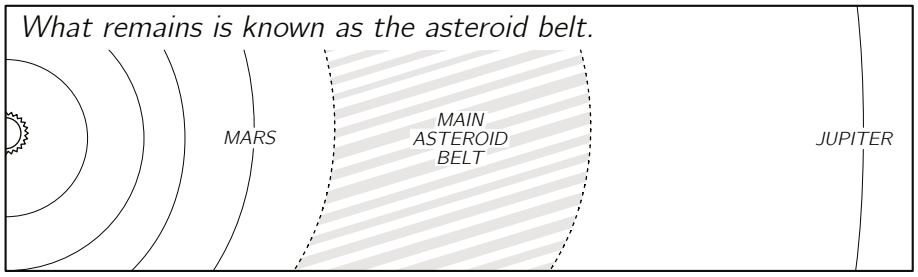
But the gravitational pull of Mars and Jupiter kept perturbing their orbits, giving them excess energy.



More than 99% of the mass was ejected from the solar system.



What remains is known as the asteroid belt.



Asteroid Facts:

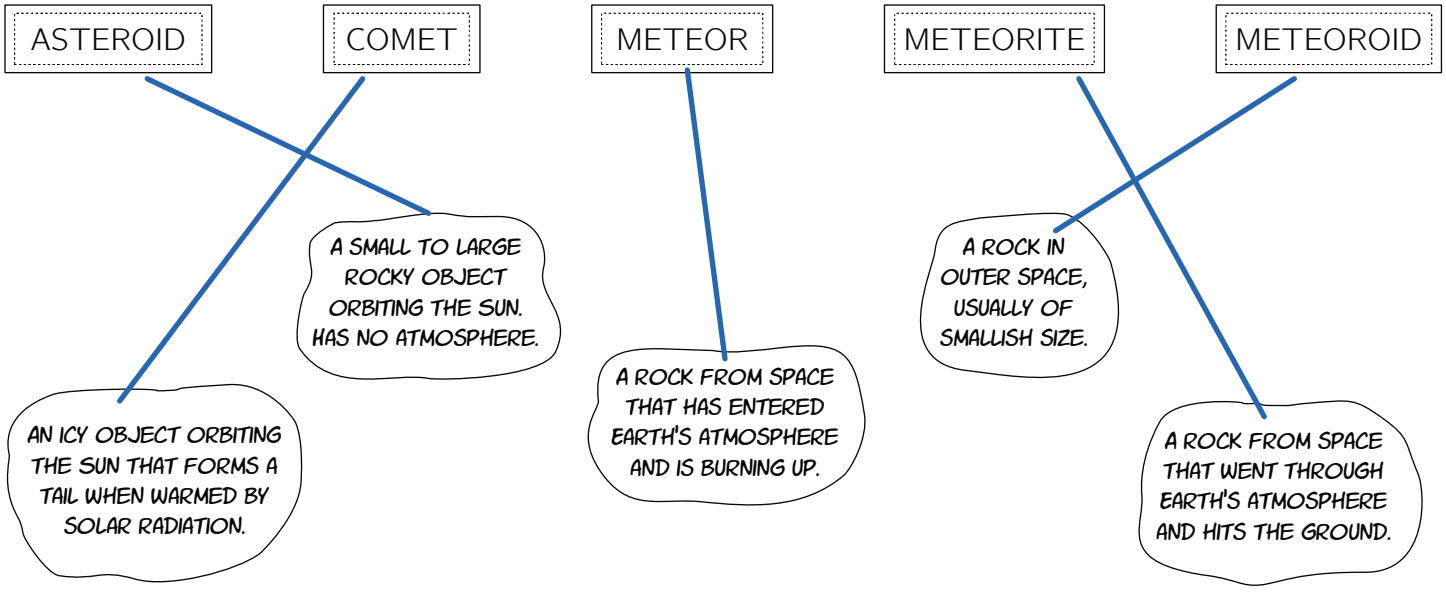
Total mass of main asteroid belt is: Less than Earth's moon. (about 4% of the Moon's mass)

Most of that mass is contained in: The 4 largest bodies: Ceres, Vesta, Pallas, Hygiea contain 60% total mass.

Number of asteroids larger than 1 km: 1 to 1.9 million

Outside the main belt, asteroids are found: Near Earth Objects (NEO), In the orbits of planets (Trojans), between Jupiter and Neptune (Centaurs), Kuiper Belt, and Oort Cloud

Match the Terms with the correct definition:



Meteorite or a meteorwrong?

Finding a meteorite is exciting because they are quite rare. Since 1900, fewer than 2,000 meteorites have been found in all of North America. Here are 3 questions to ask if you think you've found a meteorite:

- **Does it have a fusion crust?** Falling through the atmosphere forms a paper-thin glassy crust over the rock.
- **Does it feel heavy for its size?** Meteorites tend to be dense. Up to 95% of their mass can be iron, nickel, and cobalt.
- **Is it magnetic?** Stony meteorites are weakly magnetic. Stony-iron or iron meteorites are strongly magnetic.

Also, a meteorite will not have quartz crystals, bubbles or vesicles, or leave a streak when scraped across a ceramic surface.

Comets

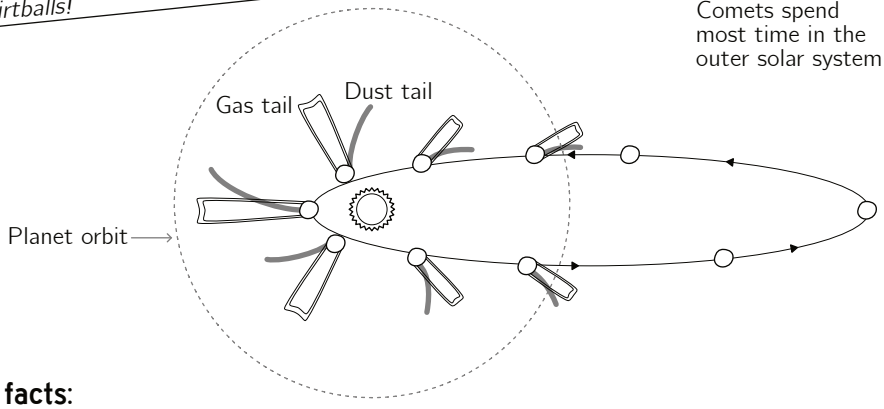
Also known as dirty snowballs or snowy dirtballs!

Composition

Comets are made of frozen "ices" such as water, methane, ammonia, carbon dioxide, and carbon monoxide. They also have dust or rocky materials.

The nucleus of the comet is usually around 10 km across or less.

As the comet gets close to the Sun it develops an envelope of gas (coma) and 2 tails.



Key facts:

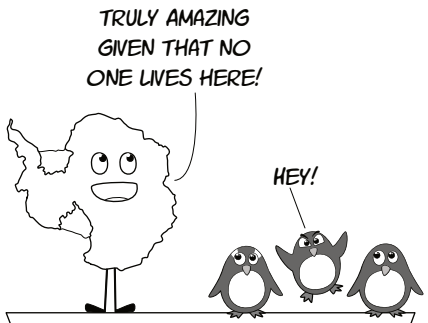
Very elliptical orbits. Only grow coma/tails when close to the Sun. Tails always point away from Sun. Comets get smaller each time they pass the Sun; as gas sublimes from them it can dislodge rocky material, forming small meteors.

Short period comets (orbits less than 200 years) are thought to come from the Kuiper belt & long period comets are thought to come from the Oort cloud.

Fact or Fiction?

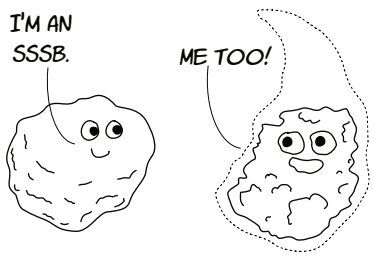
Consider each statement, then write whether it is fact or fiction.

Approximately 60% of all meteorites discovered have been found in Antarctica.



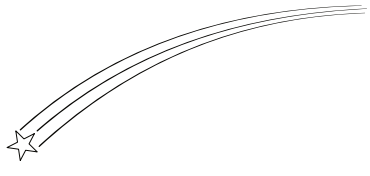
FACT: deserts have the most meteorite finds, and Antarctica is the world's biggest desert.

The term the IAU prefers for both asteroids and comets is small Solar System bodies (SSSB)



FACT

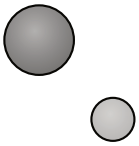
Every one of Earth's annual meteor showers are caused by our planet passing through the debris trails of comets



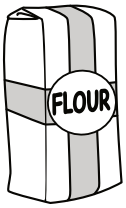
ALMOST FACT: 2 of them (Geminids and Quadrantids) are from comet-like asteroids

Crater Creator

MATERIALS

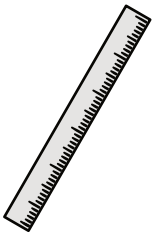


Two marbles or ball bearings of different size.

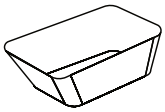


Flour

Cocoa powder



Ruler



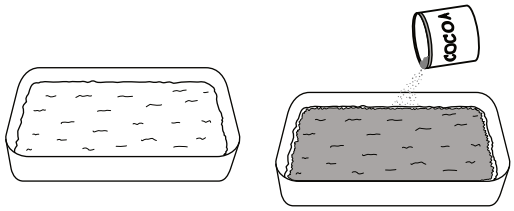
A wide non-breakable container

GOALS

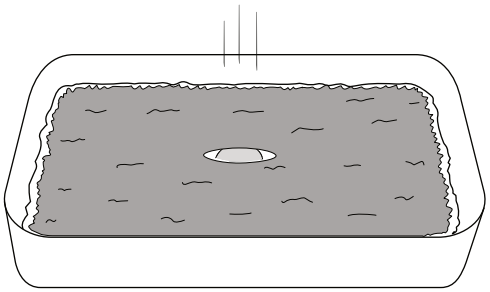
- Simulate meteors colliding with the ground.
- Formulate and test a hypothesis about meteor collisions.

How does the mass and velocity of an object affect the crater size? Design an experiment to find out!

How a Flour-Marble Model Works:



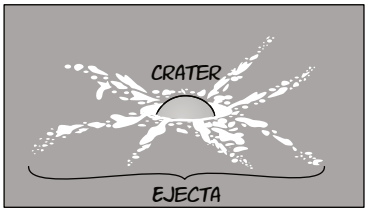
1. Pour flour into the container to a depth of three to four inches. Flatten it out by shaking or jostling the container.
2. Spread a layer of cocoa powder on the top of the flour. For best results, the layer should entirely cover the flour.
3. Drop a marble into the flour to simulate a meteor colliding with the ground.
4. Observe the impact site.
5. When the surface gets overcrowded with craters, smooth it over for another round of tests. Just apply another layer of cocoa powder before dropping more marbles.



Design Your Experiment

There are at least three things you can measure with each strike:

1. The diameter of the crater.
2. The depth of the crater, measured from flour surface to the bottom of the marble.
3. The diameter of the ejecta blanket (the white flour that has blasted out around the crater and covered the cocoa layer).



Come up with a hypothesis you would like to test. Then decide how to test the hypothesis, and carry out the test. Write up your conclusion.

Here are potential questions to help in developing a hypothesis:

- Does the speed at impact affect the depth of the craters? If yes, how? Does doubling the speed double the depth?
- Does marble mass affect the size of the craters? Does doubling the mass double the size of the crater or the ejecta?
- Does changing the mass have a bigger or smaller impact than changing the speed? In other words, what would form bigger craters, doubling the mass or doubling the speed?
- Is the crater size or ejecta blanket affected by how compact the flour is?

Note that to double the speed of the marble, you need to multiply the drop height by 4. In general, to multiply the speed by n you need to multiply the drop height by n^2.

Hypothesis

Write out your hypothesis. This is the specific claim you want to test:

Answers will vary. A good hypothesis is testable and the experiment results will either prove or disprove the hypothesis.

For example: Our hypothesis is that size has a larger influence on crater formation than speed. We predict that tripling the size will create larger craters than tripling the speed.

Methods

Describe how you will test your hypothesis. What will be measured? How will those measurements help you determine whether you hypothesis is true?

Answers will vary. Good methods should be described thoroughly enough so that someone else could recreate the experiment.

For example:

We prepared the "ground" by sliding the pan back and forth until the flour was even. Then we covered it thoroughly with cocoa powder. Our initial crater size was measured with a marble weighing 4 grams. We dropped the marble from a height of 20 cm. This was repeated 5 times so that we could get a more accurate idea of crater depth, diameter, and ejecta size.

For the next round of impact events, we prepared the flour and cocoa in the same way. Then we dropped a 12 gram marble from the same height of 20 cm. We repeated the drop 5 times and calculated the average depth, diameter, and ejecta spread.

For the last round of impact events, we prepared the flour and cocoa in the same way. Then we dropped the 4 gram marble from a height of 180 cm. By using a height that was nine times higher, the speed at impact was tripled. We repeated the drop 5 times and calculated the average depth, diameter, and ejecta spread.

Gather Data

Record your data on another piece of paper. Organize and label it neatly.

Conclusions

Were you able to confirm or disconfirm your hypothesis? What follow-up questions or tests do you recommend?

Answers will vary. Good conclusions should discuss how the data either supports or disproves the hypothesis. They should also include some reasons or explanations for the results.

For example:

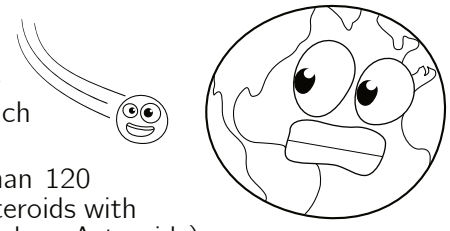
Our data disproved our hypothesis. We expected crater size to be more heavily impacted by the size of the marble than the speed, but this was not the case.

When we tripled the mass of the marble, the crater increased by ____ amount.

When we tripled the speed of the marble, the crater increased by ____ amount.

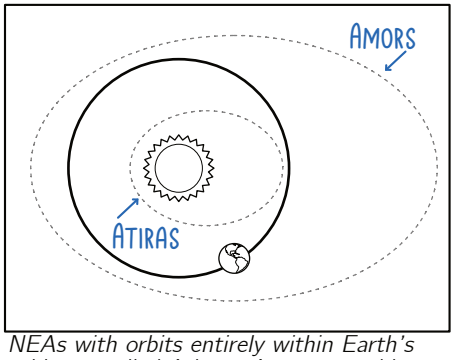
Therefore, speed or velocity has more impact than mass. If we look at the equation for kinetic energy ($KE = 1/2\ mv^2$) then we can see why this is the case. Tripling the speed multiplied the kinetic energy by a factor of nine, which causes a much larger crater.

Near Earth Objects

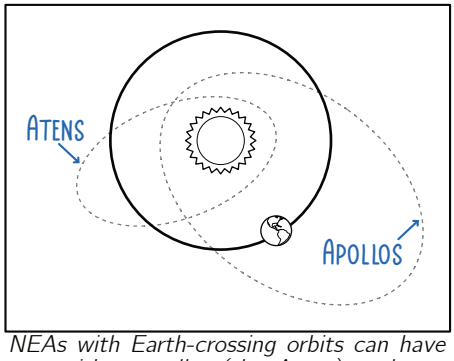


Near-Earth Objects (NEOs) are small Solar System bodies orbiting the Sun which have a perihelion approach of 1.3 AU or less.

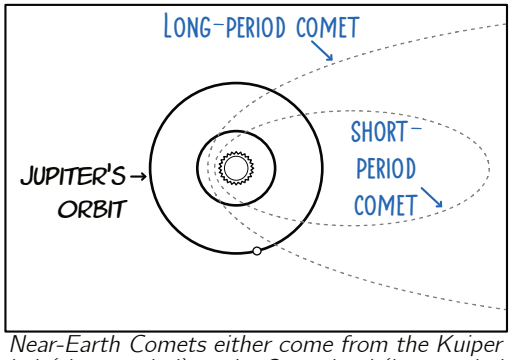
There are more than 34,000 known near-Earth asteroids (NEAs) and more than 120 near-Earth comets. Some have orbits that are outside or inside Earth's orbit. Asteroids with Earth-crossing orbits are more likely to be classified as PHAs (Potentially Hazardous Asteroids).



NEAs with orbits entirely within Earth's orbit are called Atiras. Amor asteroids have orbits between Earth and Mars.



NEAs with Earth-crossing orbits can have axes either smaller (the Atens) or larger (the Apollos) than Earth's.



Near-Earth Comets either come from the Kuiper belt(short-period) or the Oort cloud (long-period comets with an orbit of more than 200 years).

Meteor & Meteorite size, impact, and frequency

Describe the size and frequency of the meteors that cause the effects listed below:

SIZE

FREQUENCY

Every hour | Every day | Every year | Every century | Every millennium | Hundred million years or longer | Only a few times in all of Earth's history

- 1 µm *microscopic*
- 1 mm *sand*
- 1 cm *pebble*
- 1 m *boulder*
- 10 m *house*
- 100 m *field*
- 1 km
- 10 km *a small city!*

Size of meteor that can cause this effect and how often it happens:

SHOOTING STAR (brightness is similar to stars)	DUST-SIZE TO SMALL PEBBLES MOST SHOOTING STARS ARE ABOUT THE SIZE OF A GRAIN OF RICE OR A PIECE OF SAND. IMPACTS HAPPEN MULTIPLE TIMES PER HOUR ALL OVER THE WORLD. IT'S ESTIMATED THAT MORE THAN 48.5 TONS (44,000 KILOGRAMS) OF METEORITIC MATERIAL FALLS ON EARTH EACH DAY, ALMOST ALL OF WHICH IS SMALL AND VAPORIZES IN THE ATMOSPHERE.
FIREBALL (brightness greater than Venus)	DEPENDS ON COMPOSITION. MOST FIREBALLS ARE BASKETBALL TO CAR SIZE. FIREBALLS OCCUR DAILY BUT MOST OF THEM ARE MASKED BY DAYLIGHT OR OVER OCEANS, SO THEY AREN'T FREQUENTLY OBSERVED BY PEOPLE. SMALLER ONES BURN UP COMPLETELY. SMALL METEORITES (LESS THAN 1 M) THAT REACH THE GROUND (EX PEEKSHILL METEOR IN 1994) OCCUR A FEW TIMES EACH YEAR.
SIGNIFICANT ATMOSPHERIC EXPLOSION OR CRATER	HOUSE TO FIELD SIZE. THESE OCCUR A FEW TIMES PER CENTURY. EXAMPLES INCLUDE THE CHELYABINSK METEOR THAT EXPLODED OVER RUSSIA IN 2013, ESTIMATED TO BE 18M DIAMETER AND THE SULAWESI SUPERBOLIDE IN 2009.
LARGE CRATER, WIDESPREAD DEVASTATION	FIELD TO 1KM SIZE. FORTUNATELY, THESE SIZE IMPACTS ARE RARE, OCCURRING EVERY 10,000 YEARS FOR 100 M ASTEROIDS AND MORE THAN 500,000 YEARS APART FOR 1 KM ASTEROIDS. THE 1908 TUNGUSKA EVENT WAS CAUSED BY A 50-60 METER ASTEROID THAT EXPLODED AT ABOUT 10 KM ABOVE THE SURFACE. IT FLATTENED TREES OVER MORE THAN 2,000 SQUARE MILES!
MASS EXTINCTION, WORLD-WIDE EFFECTS	BIGGER THAN 1KM. FORTUNATELY, THIS SIZE OF IMPACTS ARE EXTREMELY RARE, WITH HUNDREDS OF MILLIONS OF YEARS BETWEEN IMPACTS. THE CHICXULUB IMPACTOR AT THE END OF THE CRETACEOUS PERIOD IS ESTIMATED TO HAVE BEEN ABOUT 10 KM IN DIAMETER.

Meteor Shower	Peak viewing*	Rate per hr†	Parent Body	Length of Orbit *measured in Earth years*	Next Perihelion
Quadrantids	Early January	120	Asteroid 2003 EH_1‡	5.53 years	2025
Lyrids	End of April	18	Comet C/1861 G1 Thatcher	~416 years	2283 ± 5 yrs
Eta Aquarids	Beginning of May	50	Comet 1P/Halley	76 years	2061
Southern Delta Aquarids	End of July	25	Comet 96P/Machholz	5.28 years	2028
Perseids	Mid August	100	Comet 109P/Swift-Tuttle	133 years	2125
Orionids	End of October	20	Comet 1P/Halley	76 years	2061
Leonids	End of November	15	Comet 55P/Tempel-Tuttle	33 years	2031
Geminids	Mid December	150	Asteroid (3200) Phaethon§	1.44 years	2025
Ursids	End of December	10	Comet 8P/Tuttle	13.61 years	2035

* *Exact timing changes every year and also depends on which hemisphere the viewer is in.*

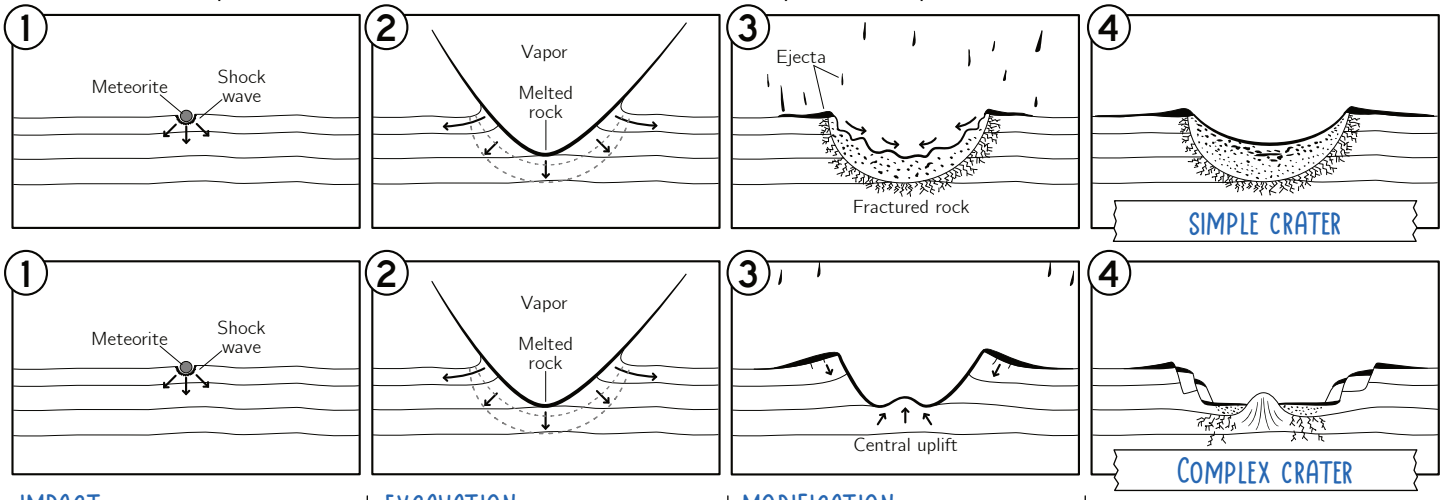
† *Rate per hour estimates from NASA. Note that meteor rate is highly variable, even for predictable showers.*

‡ *A paper in the Astronomical Journal in 2004 called 2003 EH_1 an intermittently active comet. In other sources, it's called an asteroid*

§ *Phaethon acts like a comet, brightening and forming a tail when it's near the Sun. But this tail seems to be mostly sodium gas.*

What happens on impact?

Describe the steps of crater formation and label which is complex vs simple.



IMPACT

METEOR MAKES CONTACT AND COMPRESSES THE TARGET ROCK.

EXCAVATION

CRATER EXCAVATION, MELTED ROCK IS THROWN INTO AIR, DISINTIGRATION OF METEORITE

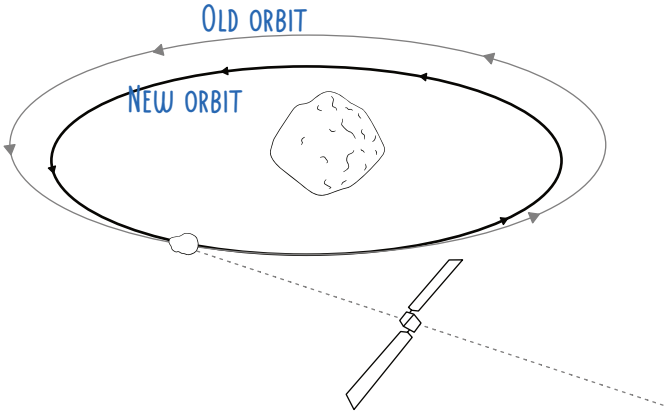
MODIFICATION

FRACTURING OF ROCK OR CENTRAL UPLIFT OCCURS

FINAL SHAPE: SIMPLE CRATERS ARE BOWL SHAPED. COMPLEX CRATERS HAVE A CENTRAL PEAK AND ARE FORMED BY A LARGER AND MORE POWERFUL IMPACT

PanSTARRS and DART

DOUBLE ASTEROID REDIRECTION TEST (DART)TARGETED ASTEROID DIDYMOS AND ITS MOONLET DIMORPHOS. THE TEST SHOWED THAT (WITH ENOUGH WARNING) WE COULD DEFLECT A POTENTIALLY HAZARDOUS ASTEROID AND PREVENT IT FROM HITTING EARTH. PANSTARRS IS THE LARGEST NEO DETECTION TELESCOPE SYSTEM.



Solar System Review

IN YOUR OWN WORDS!

Learning and understanding new words is an important part of astronomy! Define each of the following terms in your own words. If the word has a box next to it, use that space to draw and label a diagram.

ASTEROID: Asteroids are made of rocky material. They're not large enough to be round under the force of their own gravity (ie smaller than 600 km diameter).

BOLIDE: Large meteors that explode in the atmosphere.

COMET: Made of both icy and rocky material. Sometimes called dirty snowballs or snowy dirtballs. They formed further out from the Sun where there was more icy material like frozen water, methane, and ammonia.

ELIPSE: An oval shape where the sum of the distances from two focal points is always the same. A circle is a special type of elipse where the 2 focal points are the same.

FIREBALL: A very bright meteor that shines more brightly than the stars as it travels through the atmosphere.

METEOR: A rocky object from outer space that has entered Earth's atmosphere. Friction with the air makes it glow brightly. Small meteors are called "shooting stars." Larger meteors are called "fireballs."

METEORITE: A rocky object from outer space that survived its descent through Earth's atmosphere and made impact with the ground.

NEBULA: A collection or cloud of gas and dust particles in outer space.

PARALLAX: The effect that makes the position or direction of an object appear differently when viewed from a different position. IE when passing a car on the freeway the car appears to travel backwards relative to the viewer while it's being passed.

PROTOPLANETARY DISK: A rotating disk of gas and dust surrounding a newly-forming star. The birthplace of stars, planets, asteroids, and comets!

1. Which planet has the highest density in our solar system?
   A. Jupiter
   B. Earth
   C. Mars
   D. Venus

2. The asteroid belt is primarily located between which two planets?
   A. Mars and Jupiter
   B. Earth and Mars
   C. Jupiter and Saturn
   D. Venus and Earth

3. Which planets have a stronger magnetic field than Earth?
   A. Mercury
   B. Venus
   C. Mars
   D. Jupiter
   E. Saturn
   F. Uranus
   G. Neptune

4. Which statement about the Sun is FALSE?
   A. It contains about 99.86% of the solar system's mass
   B. It is classified as a red giant star
   C. It produces energy through nuclear fusion
   D. Its core temperature is about 15 million degrees Celsius

5. The Great Red Spot is a feature found on which planet?
   A. Mars
   B. Venus
   C. Jupiter
   D. Saturn

6. Which of the following are dwarf planets?
   A. Ceres
   B. Pluto
   C. Eris
   D. Hale-Bopp
   E. Makemake

7. What is the primary component of Saturn's rings?
   A. Rocky debris
   B. Ice particles
   C. Metallic dust
   D. Frozen methane

8. Which planet rotates "backwards" compared to most other planets?
   A. Uranus
   B. Venus
   C. Neptune
   D. Mars

9. The Kuiper Belt is primarily composed of:
   A. Metallic asteroids
   B. Gas clouds
   C. Icy bodies
   D. Dust particles

10. How many Earth years long would a year be on a planet with a circular orbital radius of 4 AU?
    A. 2 Earth years
    B. 4 Earth years
    C. 8 Earth years
    D. 16 Earth years

11. What is the name of Mars' largest moon?
    A. Ganymede
    B. Phobos
    C. Deimos
    D. Io

12. Olympus Mons, the largest known volcano in the solar system, is located on:
    A. Venus
    B. Mars
    C. Mercury
    D. Io

13. What phenomenon causes the appearance of Saturn's rings to change as viewed from Earth?
    A. Saturn's rotation
    B. Saturn's orbital tilt
    C. Solar wind
    D. Atmospheric distortion

14. Which planet's atmosphere contains the highest percentage of carbon dioxide?
    A. Mercury
    B. Venus
    C. Earth
    D. Mars
    E. Jupiter
    F. Saturn

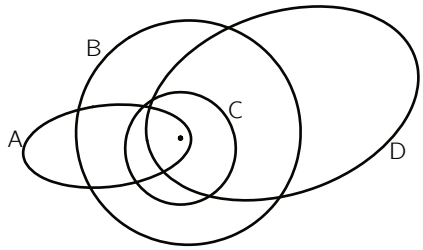
15. What is the approximate time it takes for sunlight to reach Mars?
A. 1.5 minutes
B. 6 minutes
C. 12.5 minutes
D. 20 minutes

16. The Cassini Division is:
A. A gap in Saturn's rings
B. A region of the asteroid belt
C. A crater on Mercury
D. A zone in Jupiter's atmosphere

17. Which planet was discovered through mathematical calculations before it was observed?
A. Uranus
B. Neptune
C. Saturn
D. Mars

18. The surface of Venus is obscured by clouds primarily composed of:
A. Water vapor
B. Methane
C. Sulfuric acid
D. Ammonia

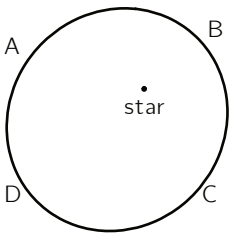
19. The orbits are shown for objects A, B, C, and D. Place them in order from shortest year (full orbit) to longest year.



THE SMALLER THE MEASURE OF THE MAJOR AXIS, THE FASTER THE PLANET WILL COMPLETE THE ORBIT.

YEAR FOR C < YEAR FOR A < YEAR FOR B < YEAR FOR D

20. Four different points are shown along the orbit of a planet, labeled A, B, C, and D. At which point is the planet moving fastest?



A. A
B. B
C. C
D. D
E. The planet is always moving the same speed along the orbit.

THE FASTEST SPEED OCCURS CLOSE TO THE STAR.

21. Mercury's "day" (one full rotation on its axis) is approximately how long compared to its "year" (one orbit around the Sun)?
A. 1/4 of a Mercurial year
B. 2/3 of a Mercurial year
C. 2 Mercurial years
D. 3 Mercurial years

22. What causes the blue color of Neptune?
A. Water reflection
B. Methane in its atmosphere
C. Surface ice
D. Nitrogen compounds

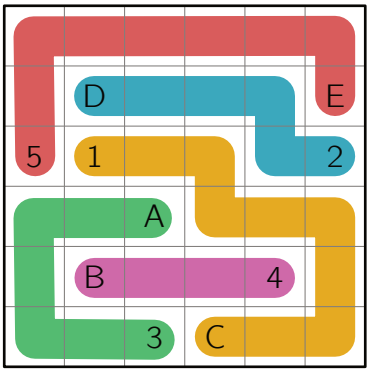
23. Which moon is the only one known to have a thick atmosphere?
A. Europa
B. Callisto
C. Ganymede
D. Titan

24. The Galilean moons are associated with which planet?
A. Saturn
B. Jupiter
C. Uranus
D. Neptune

25. Which planet has the shortest day (rotation period)?
A. Mercury
B. Venus
C. Mars
D. Jupiter

26. Mark each statement as true or false.
T [F] Half of the Moon never receives sunlight.
[T] F The same side of the Moon is always facing the Earth.
T [F] Mercury is the hottest planet in the solar system.
T [F] The asteroid belt contains more total mass than Earth's moon.
[T] F Venus rotates in the opposite direction compared to most other planets.
[T] F Uranus has the greatest tilt in its orbit of any planet.
[T] F A day on Mars is about the same length as a day on Earth.
[T] F Saturn is less dense than liquid water.

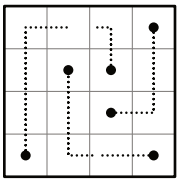
Pipe Flow Matching - Moons



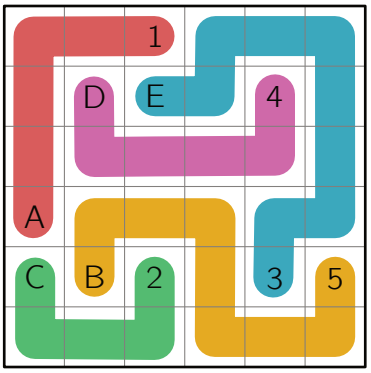
Rank the planets below by number of moons and join the corresponding letter and number with a continuous stroke. Each square in the grid should be visited by exactly one pipe as in the example grid shown below.

1. Mars
2. Earth
3. Saturn
4. Jupiter
5. Venus

A. Most moons
B. Second most moons
C. Third most moons
D. Fourth most moons
E. Fewest moons



Pipe Flow Matching - Planet Facts 1

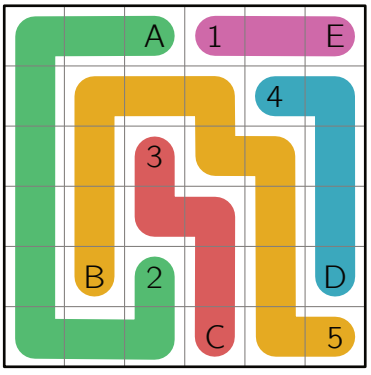


Which planet is the hottest, spins the fastest, and is the most in other categories? Join each planet with its corresponding award with a continuous stroke (pipe). Each square in the grid should be visited by exactly one pipe.

1. Jupiter
2. Earth
3. Venus
4. Mars
5. Neptune

A. Spins the fastest
B. Strongest winds
C. Most dense planet
D. Largest volcano
E. Hottest planet

Pipe Flow Matching - Planet Facts 2

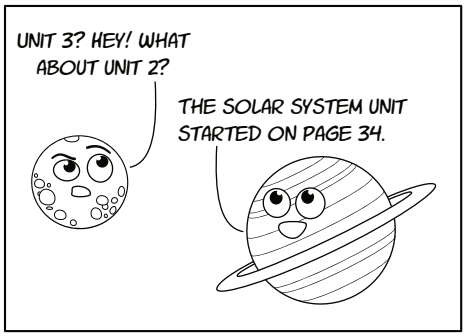


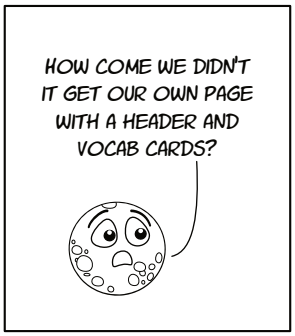
Which planet rotates sideways? Which one has moons that can be seen with binoculars? Join each planet with its corresponding award with a continuous stroke (pipe). Each square in the grid should be visited by exactly one pipe.

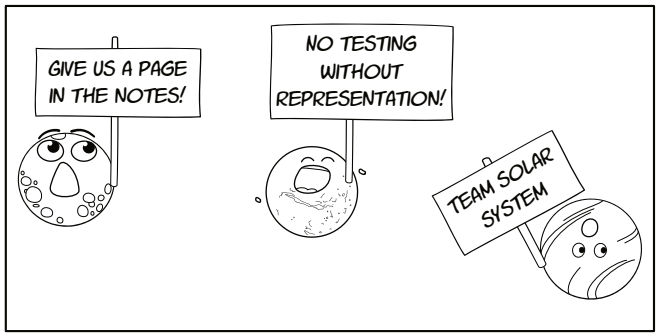
1. Uranus
2. Mercury
3. Jupiter
4. Mars
5. Venus

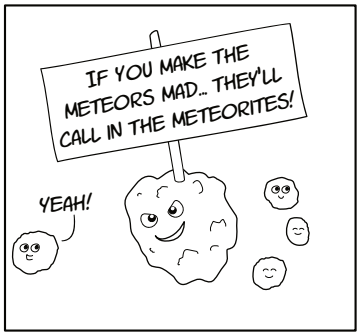
A. Shortest year
B. Is closest to Earth
C. Moons visible with binoculars
D. Has snow (made of carbon dioxide)
E. Rotates sideways

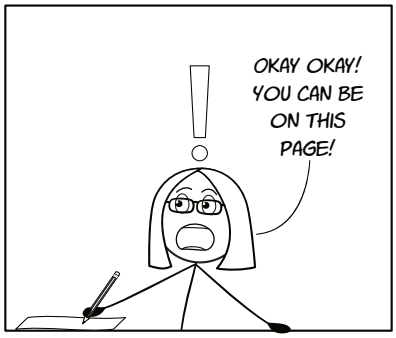
Unit 3: Stars, Galaxies, & our Universe





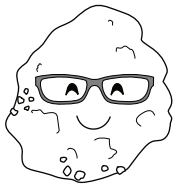






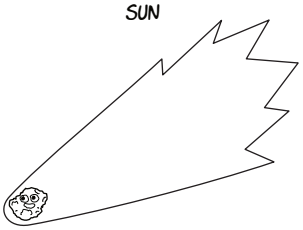
A SELECTION OF UNIT 2 VOCABULARY TERMS

A SMALL SOLAR SYSTEM BODY THAT IS PRIMARILY MADE OF ROCKY MATERIAL



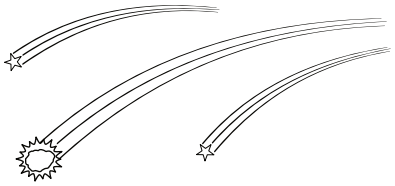
ASTEROID

AN ICY, SMALL SOLAR SYSTEM BODY THAT FORMS A TAIL WHEN NEAR THE SUN



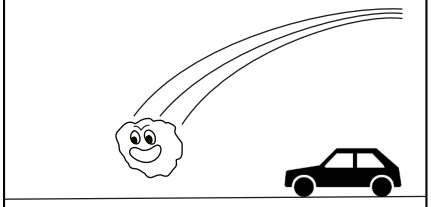
COMET

A ROCK FROM SPACE THAT HAS ENTERED EARTH'S ATMOSPHERE. IF SMALL, OFTEN CALLED A "SHOOTING STAR."



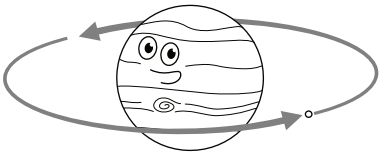
METEOR

A ROCK FROM SPACE THAT HAS PASSED THROUGH EARTH'S ATMOSPHERE AND IMPACTED THE GROUND



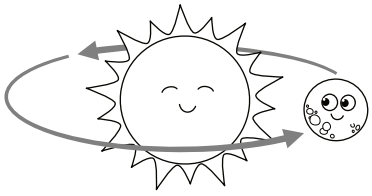
METEORITE

AN OBJECT ORBITING A PLANET OR SOMETHING ELSE THAT IS NOT A STAR



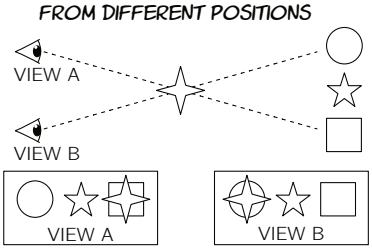
MOON

AN OBJECT ORBITING A STAR THAT IS ROUND DUE TO ITS OWN GRAVITY,



PLANET

WHEN THE POSITION OF AN OBJECT APPEARS DIFFERENT WHEN VIEWED FROM DIFFERENT POSITIONS



PARALLAX

Draw illustrations for these Unit 3 vocabulary terms!

A GROUP OF STARS THAT FORMS A VISIBLE PATTERN IN THE NIGHT SKY

ASTERISM

A REGION IN OUTER SPACE WHERE THE GRAVITY IS SO EXTREME THAT LIGHT CANNOT ESCAPE

BLACK HOLE

THE OUTERMOST LAYER OF THE SUN, IT'S ATMOSPHERE.

CORONA

THE PROCESS WHERE ATOMIC NUCLEI COMBINE TO FORM A HEAVIER NUCLEUS, RELEASING ENERGY

FUSION

A GROUP OF STARS, DUST, AND GAS BEING HELD TOGETHER BY GRAVITY

GALAXY

THE UNIT OF DISTANCE THAT LIGHT TRAVELS IN ONE EARTH YEAR. EQUIVALENT TO 9.4 TRILLION KM

LIGHT YEAR

THE AMOUNT OF LIGHT ENERGY EMITED BY A STAR

LUMINOSITY

THE BRIGHTNESS OF A STAR VIEWED FROM EARTH

ABSOLUTE MAGNITUDE

THE BRIGHTNESS OF A STAR IF VIEWED FROM 10 PARSECS AWAY

APPARENT MAGNITUDE

A SPHERE OF GAS THAT GENERATES HEAT AND LIGHT FROM FUSION

STAR

AN EXPLOSION OF A MASSIVE STAR AS IT COLLAPSES AT THE END OF ITS LIFE

SUPERNOVA

THE POINT IN THE SKY OR CELESTIAL SPHERE DIRECTLY ABOVE AN OBSERVER.

ZENITH

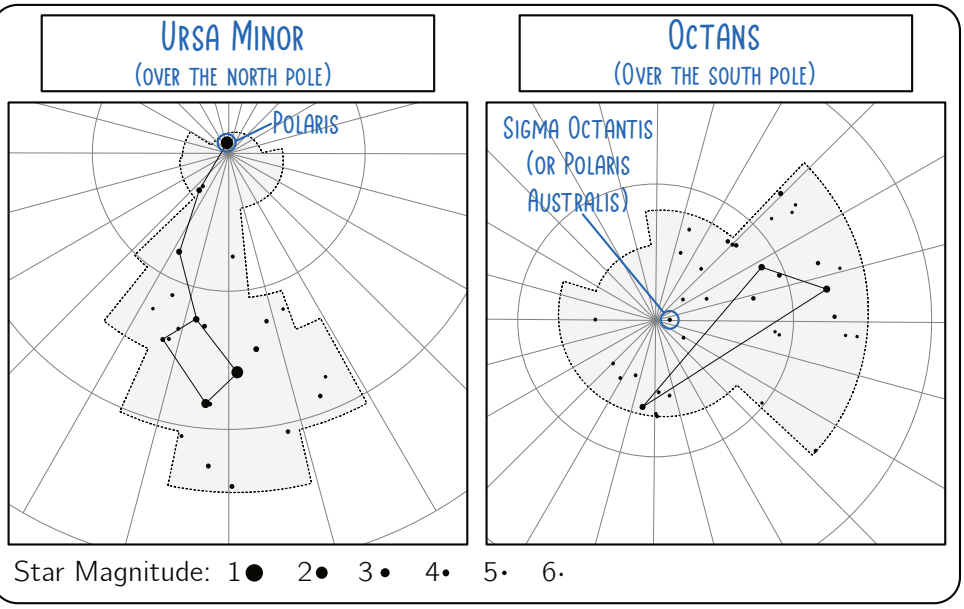
The Constellations

Land within a country is often split into *states* or *provinces*. In a similar method, our view of the sky has been divided into 88 regions called *constellations*.

The two images on the right show the constellations around the pole stars using a spherical projection.

Label each constellation and identify the pole stars (Polaris and Sigma Octantis.)

The rectangular map below shows all 88 constellations in the entire sky– but our sky is round and the map is a rectangle. As a result, the polar constellations look especially stretched.

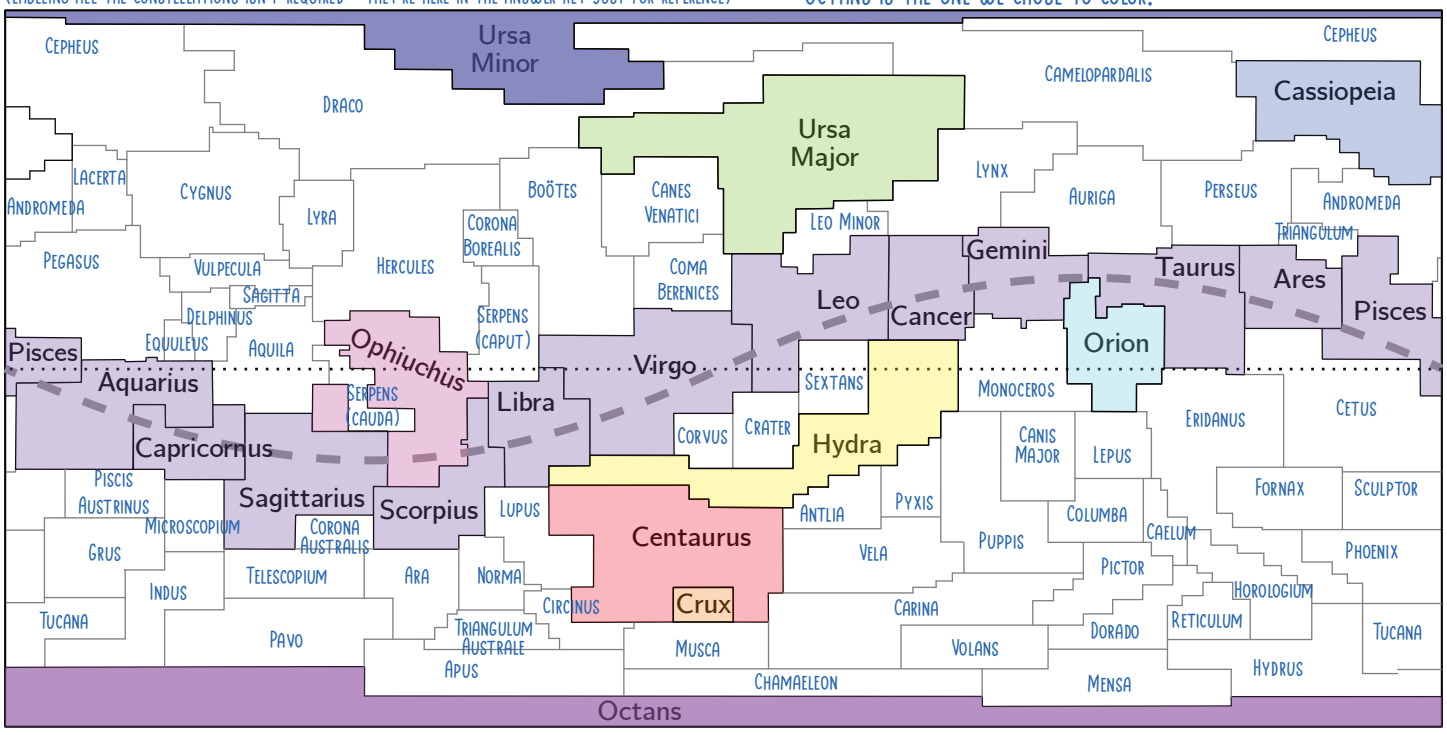


Identify the Constellations:
Use colored pencils or crayons to color the constellations that fit the following descriptions from the map below. Choose a different color for each category.

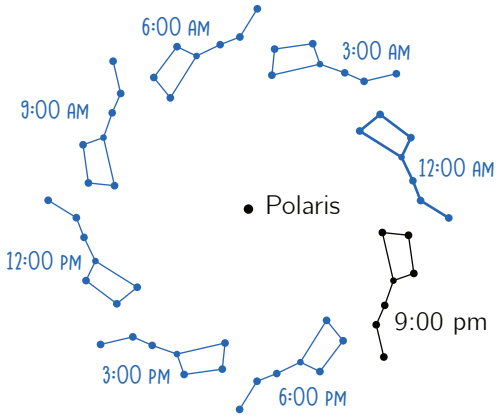
- *On the ecliptic and a zodiac sign*
- *On the ecliptic but not a zodiac sign*
- *Contains the nearest star to our solar system*
- *Contains the famous "Southern Cross" asterism*
- *The largest and longest constellation*
- *The largest constellation in the Northern Hemisphere*
- *Contains a red giant, blue giant, and famous nebula*
- *Contains a famous "W" asterism*
- *Contains a bright star that doesn't appear to move*
- *Only has 1 star brighter than magnitude 4*

(labeling all the constellations isn't required – they're here in the answer key just for reference)

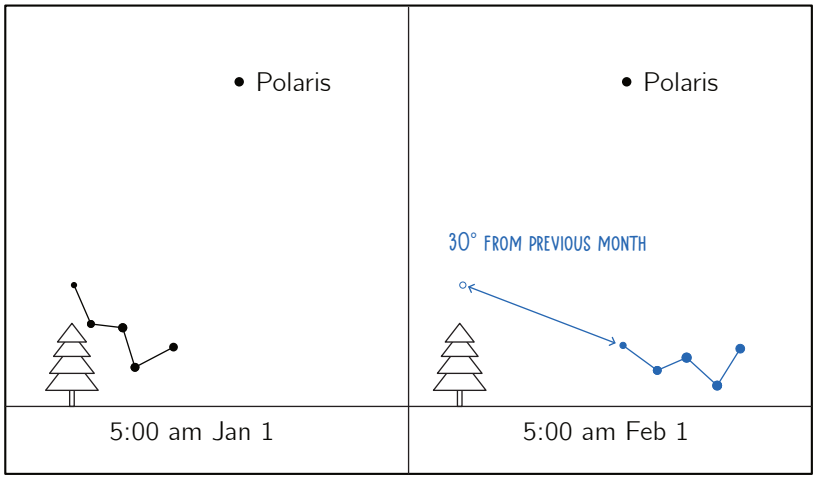
There are several constellations that fit this description! Octans is the one we chose to color.



Navigation and Telling Time:

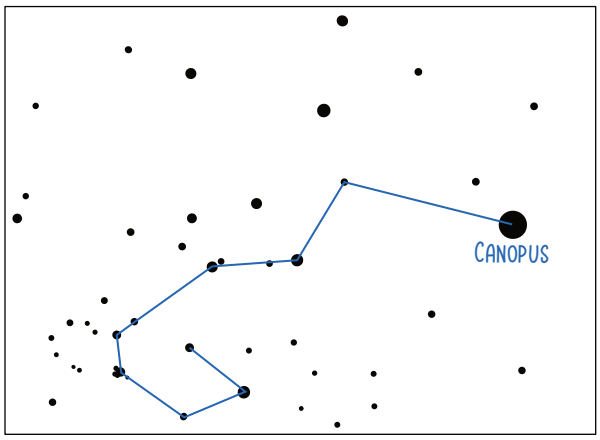


The Big Dipper asterism is located as drawn above at 9 pm. At midnight, where would you expect to see the Big Dipper?



Use the position of Cassiopeia on Jan 1 to plot where the constellation will appear in the sky on Feb 1.

Mythology:



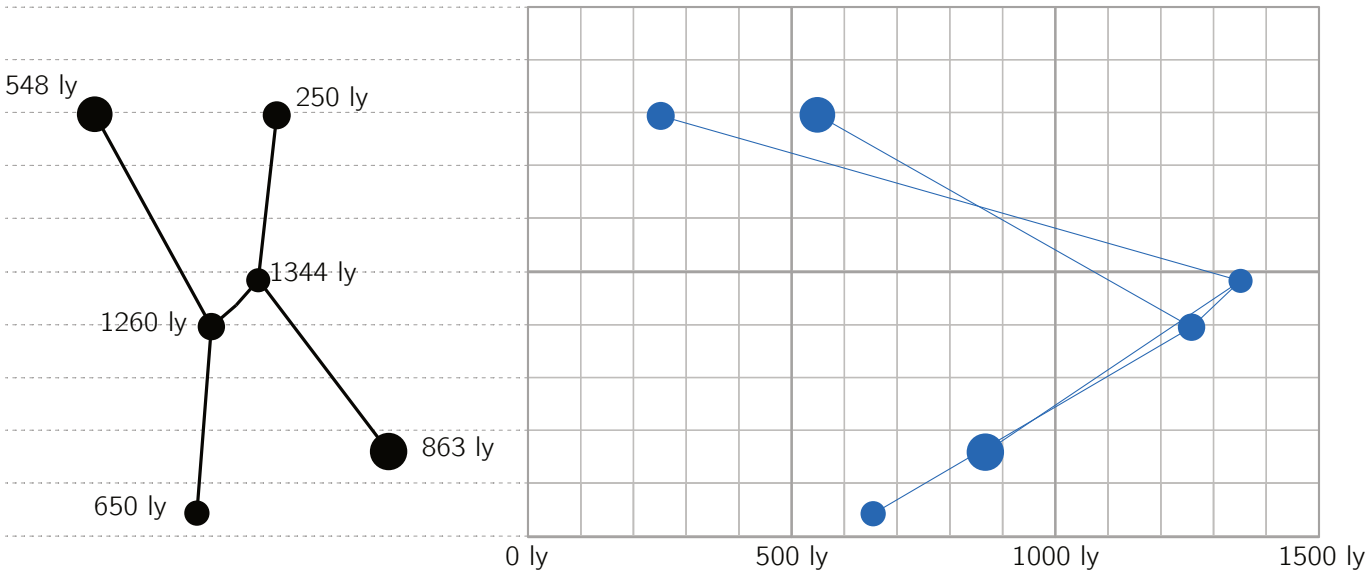
How would you remember this star pattern or describe it to someone else?

ANSWERS WILL VARY! ANY ASTERISM OR STORY THAT HELPS WITH RECOGNIZING THE PATTERN IS VALID.

THIS ASTERISM DRAWN HERE IS FROM THE CONSTELLATION CARINA. BUT STARS FROM THE CONSTELLATIONS PUPPIS AND VELA ARE ALSO SHOWN. CANOPUS IS LOCATED IN THE SOUTHERN HEMISPHERE. IT'S THE 2ND BRIGHTEST STAR IN THE NIGHT SKY.

Perspective is Everything!

What would these stars from Orion look like from a different direction? Plot the side view on the axis to the right using the distances shown. (Keep the vertical component the same.)



Stargazing 101

Textbooks and simulations can teach you a lot about stars, but nothing quite compares to seeing them yourself! Stargazing is essential for a student of astronomy. It will sharpen observational skills, awaken curiosity, and reinforce concepts learned.

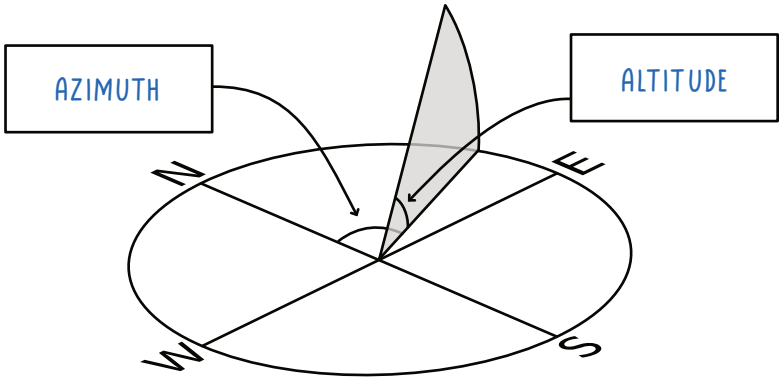
3 tips for successful stargazing:

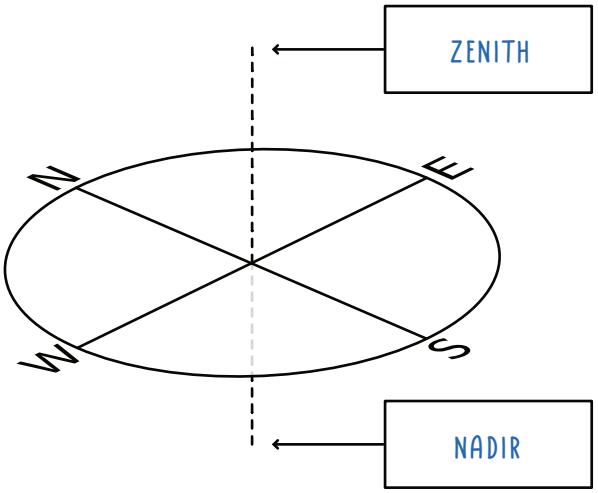
1. Find dark skies, if possible. Light pollution hides stars from view. Traveling away from a city center can reveal hundreds of additional stars.
2. Prepare in advance. Look up the constellations and planets which will be visible for your location and time of year. Free apps such as Sky Guide or SkyView can be very helpful for this. The Stellarium website is also a wonderful resource for exploring the night sky from your location. https://stellarium-web.org/
3. Become familiar with the celestial sphere and angles!

Fill in the blanks

celestial *azimuth* *altitude* *zenith* *horizon* *nadir*

AZIMUTH is the angle measured clockwise from the north point on the HORIZON to the point directly below the star, ranging from 0° to 360°. ALTITUDE (or elevation) describes the star's angle above the horizon, varying from 0° at the horizon to 90° at the ZENITH, which is the point directly overhead. The NADIR is the point directly below the observer, opposite the zenith. These measurements are made on the CELESTIAL sphere.

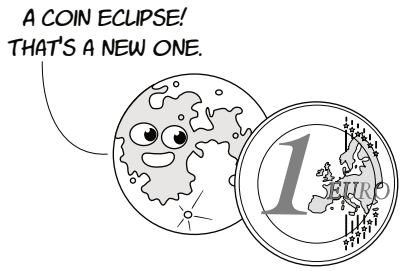




Fact or Fiction?

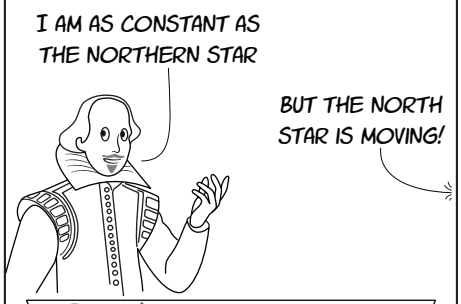
Consider each statement below. Is it fact or fiction?

A coin held at arms length would closely match the size of the Moon in the sky



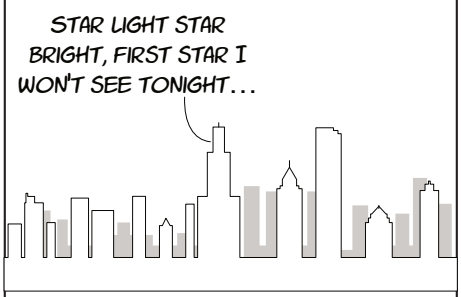
FALSE The correct size to just eclipse the moon is ½ of a degree. That's ½ the size of your pinkie finger at arms length.

In about 200 years, Polaris will no longer be the North Star. Instead, it will be Vega.



FALSE (True fact but wrong timeline) Vega will become the new north star due to Earth's procession about 11,000 years from now.

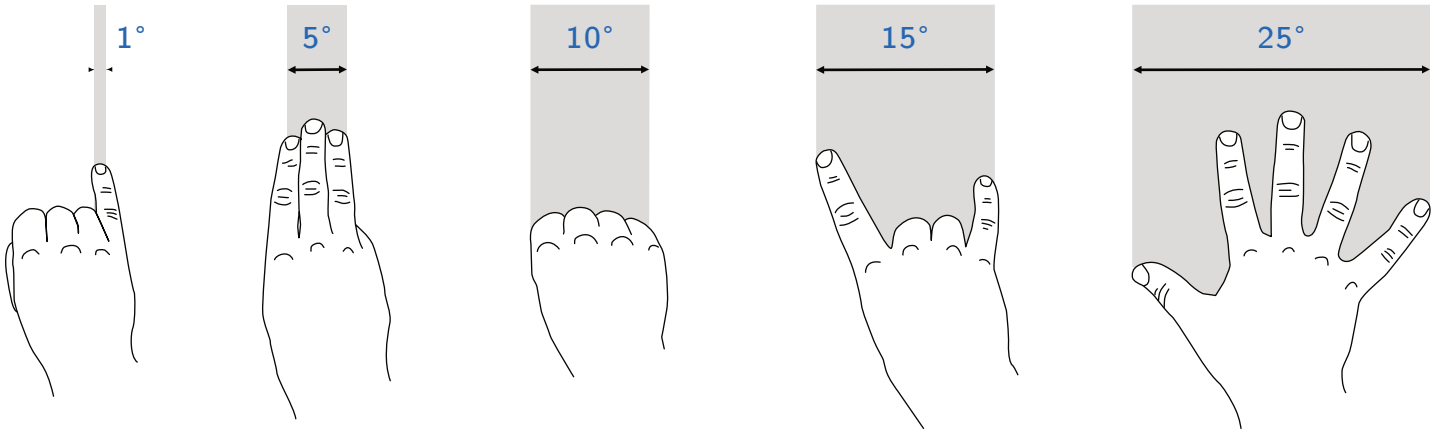
Artificial city lights contribute to light pollution which has negative impacts



FACT Excess lights disrupt circadian rhythms and interfere with migrations, especially around urban areas.

How many degrees?

Arms and hands are useful tools for measuring angles! Record the angles associated with each hand position below (when held at arm's length).



When facing directly north, a bright star is observed to be 3 fists above the horizon. What is the altitude and azimuth of this star?

The azimuth is 0°. The altitude is 30°

When facing directly east, a star is observed to be 3 fingers above the horizon. What is the altitude and azimuth of this star?

The azimuth is 90°. The altitude is 5°

Will the altitude and azimuth of these stars be different in one hour? If so, why and how?

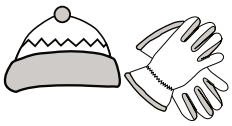
Yes. Because the earth is rotating. In 1 hour the position of all stars will be in different apparent locations except for polar stars. Polar stars are aligned with the axis of Earth so as it spins they don't appear to move.

Stargazing

MATERIALS


Outdoor location


Red flashlight
(or a regular flashlight covered with red cellophane or paper)


Warm clothing


Binoculars or a telescope (optional)


Stargazing printouts or paper and a pencil for taking notes

GOALS

- Become more familiar with the night sky
- Experience a sense of wonder and awe for the scale of the universe
- Learn to recognize the differences between planets, stars, galaxies, comets, meteors, and artificial satellites

There's no substitute for getting outside and looking up at the night sky! Stargazing can teach you so much. But it can also be a challenging endeavor. Light pollution can hide stars from view and a need for sleep and warmth can make it difficult to spend time under a dark sky.

To add a little bit of fun, we've made a stargazing scavenger hunt. You're invited to go stargazing 5 times during this class. Each time you go, fill in the information in the stargazing log to summarize your experience. Then color in stars on the scavenger hunt page for each celestial object you're able to find. Depending on your location and resources, it may not be possible to observe them all. Do what you can and celebrate each milestone you reach!

Tip 1: Dress in layers

One of the biggest challenges to stargazing is keeping warm. When out in cold weather, **it is essential to wear layers**. Other tools like hand-warmers or having food and hot drinks can also help. But wearing layers is crucial! Adjust the layers (putting more on or taking a layer off) as needed to stay comfortable.

- WEAR AT LEAST 3 LAYERS (BASE, MIDDLE, and OUTER)
- ADD ADDITIONAL LAYERS IF NEEDED (ex, 2 coats, rain gear)
- SAY YES TO GLOVES, HATS, and INSULATED BOOTS

THERE'S NO SUCH THING AS BAD WEATHER, JUST BAD CLOTHING!

What I wear for cold weather (0-10 °C, or 32-45 °F)


BASE LAYER: thermals + wool socks


MID LAYER: warm clothes


OUTER LAYER: coat, snow pants, gloves, hat, and insulated boots

What I wear for very cold weather (Less than 0 °C or 32 °F)


BASE LAYER: thermals + thin socks to go under wool socks


MID LAYER: regular clothes, wool socks, fleece jacket & puffy coat, sweat pants or snow pants


OUTER LAYER: big coat, rain pants, 2 pr gloves, hat, insulated boots

Tip 2: There are different types of fun

Have you had an experience that was unpleasant while it was happening, but you remember it fondly?

This is "type 2 fun," and it is often the most rewarding or fulfilling kind of experience.

Stargazing in cold weather is often type 2 fun. Talking about this "fun scale" in advance can be helpful in setting expectations and making a better experience overall.

TYPE 1 FUN

Fun in the moment and also fun to remember

Eating good food, playing games with friends, playing a favorite sport

TYPE 2 FUN

Unpleasant while happening but fun in retrospect

Long distance running, survival camping, hiking to the top of a very tall mountain

TYPE 3 FUN

Not fun, even in retrospect, but makes a good story

Writing a book, getting frostbite, disasters and catastrophes

How Dark is Your Sky?

The Bortle dark-sky scale measures the quality of the night sky for stargazing. It ranges from class 1 (the darkest skies available on Earth) to class 9 (inner-city skies with the most light pollution).

Amateur astronomer John Bortle created the scale in 2001. It's commonly used to compare the darkness of different observation sites. To figure out where your observation site ranks on the Bortle scale, pay special attention to the visibility of the Milky Way and zodiacal light.

The Milky Way

Our galaxy is named for how we see it from Earth! It's a spiral galaxy where most of the stars are concentrated along a galactic plane.

From Earth, this plane looks like a hazy band of white light, about 30° wide, that arches across the entire night sky.

The reason it looks "milky" is because it contains so many stars we can't *resolve* them – we can't distinguish the individual stars from each other. Instead, we see a blurry band that is noticeably brighter than the rest of the night sky.

Zodiacal Light

Zodiacal light is the glow of sunlight that has been scattered by interplanetary dust.

It's only visible in dark or rural skies and appears along the ecliptic. It's brightest and most obvious before sunrise (when it's called "false dawn") or after sunset. It extends from the horizon in a roughly triangular shape and is less bright near the zenith.

While zodiacal light can span the entire ecliptic and contribute to the natural light of a clear sky, it's very faint. It is not visible when there is moonlight or light pollution from city lights.

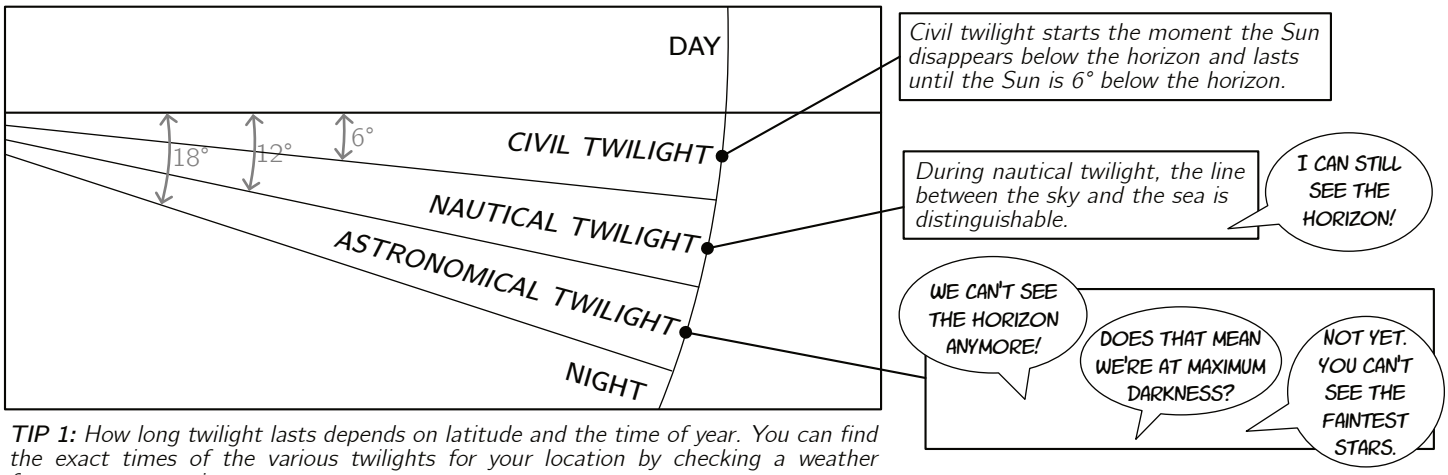
1	2	3	4
EXCELLENT DARK SKY	**DARK SKY**	**RURAL SKY**	**BRIGHTER RURAL SKY**
Zodiacal light is visible and colorful; it extends across the entire ecliptic. Constellations are hard to recognize because there are so many stars. Messier objects and globular clusters are visible to the naked eye.	Zodiacal light is visible and the Milky Way is highly structured. Many Messier objects are visible to the naked eye. Clouds are only visible as dark holes in night sky.	Zodiacal light is visible but does not extend to zenith. Many Messier objects are visible to the naked eye. Clouds are lightly-colored or illuminated on the horizon, but dark when overhead.	Zodiacal light sometimes visible. Light pollution domes visible in multiple directions. Milky Way is visible but lacks detail. Clouds are noticeably brighter than the night sky.
M33 easily visible with naked eye	*M33 visible with direct vision*	*M33 only visible with averted vision*	*M33 not visible*

5	6	7	8	9
SUBURBAN SKY	**BRIGHT SUBURBAN**	**URBAN TRANSITION**	**CITY SKY**	**INNER CITY SKY**
Light pollution is visible in most directions. Clouds are noticeably brighter than the night sky. The Milky Way is not visible on the horizon and faint or washed out at the zenith.	Clouds are brighter than the sky. Light pollution domes give the sky a grey-white glow up to 30° from the horizon. The Milky Way is either not visible at all or only faintly visible at the zenith.	Light pollution gives the entire sky a grey color. Clouds are brightly lit. Milky Way is not visible. The bright stars of constellations are visible but many other are not.	The entire night sky appears light grey or orange. Stars that form most of the constellations are faint or invisible.	The only observable objects in the night sky are the Moon, the planets, and perhaps a few of the brightest stars.

M33 not visible →

When viewing the night sky from your home, what rating does it have on the Bortle scale? Use the above descriptions to decide!

Have you ever visited an area with darker skies? If so, where?



TIP 1: *How long twilight lasts depends on latitude and the time of year. You can find the exact times of the various twilights for your location by checking a weather forecast or stargazing app.*

TIP 2: *Use a red flashlight to write notes or color in the scavenger pages! The cone cells adapt to darkness within about 10 minutes but the rod cells in human eyes take at least 40 minutes to adapt to low light conditions. If you look at white light, you lose your "night vision" or peak sensitivity to light and it takes a long time to build it back up. A dim red light allows you to see a bit better while still keeping your night vision.*

Stargazing Log

1 ☐

Date: _____

Temperature:
☐ Crazy cold ☐ Cold ☐ Comfortable ☐ Warm

Time (start to end): _____

Fun Factor Rating:
☐ Type 1 ☐ Type 2 ☐ Type 3

Twilight or night? _____

Draw an asterism or constellation you observed!

Moon (if visible, phase) _____

Observational tools: ☐ Naked eye ☐ Binoculars ☐ Telescope

How dark was the sky on the Bortle scale?

1 2 3 4 5 6 7 8 9

2 ☐

Date: _____

Temperature:
☐ Crazy cold ☐ Cold ☐ Comfortable ☐ Warm

Time (start to end): _____

Fun Factor Rating:
☐ Type 1 ☐ Type 2 ☐ Type 3

Twilight or night? _____

Draw an asterism or constellation you observed!

Moon (if visible, phase) _____

Observational tools: ☐ Naked eye ☐ Binoculars ☐ Telescope

How dark was the sky on the Bortle scale?

1 2 3 4 5 6 7 8 9

3 ☐

Date: _____

Time (start to end): _____

Twilight or night? _____

Moon (if visible, phase) _____

Observational tools: ☐ Naked eye ☐ Binoculars ☐ Telescope

How dark was the sky on the Bortle scale?

1 2 3 4 5 6 7 8 9

Temperature:

☐ Crazy cold ☐ Cold ☐ Comfortable ☐ Warm

Fun Factor Rating:

☐ Type 1 ☐ Type 2 ☐ Type 3

Draw an asterism or constellation you observed!

4 ☐

Date: _____

Time (start to end): _____

Twilight or night? _____

Moon (if visible, phase) _____

Observational tools: ☐ Naked eye ☐ Binoculars ☐ Telescope

How dark was the sky on the Bortle scale?

1 2 3 4 5 6 7 8 9

Temperature:

☐ Crazy cold ☐ Cold ☐ Comfortable ☐ Warm

Fun Factor Rating:

☐ Type 1 ☐ Type 2 ☐ Type 3

Draw an asterism or constellation you observed!

5 ☐

Date: _____

Time (start to end): _____

Twilight or night? _____

Moon (if visible, phase) _____

Observational tools: ☐ Naked eye ☐ Binoculars ☐ Telescope

How dark was the sky on the Bortle scale?

1 2 3 4 5 6 7 8 9

Temperature:

☐ Crazy cold ☐ Cold ☐ Comfortable ☐ Warm

Fun Factor Rating:

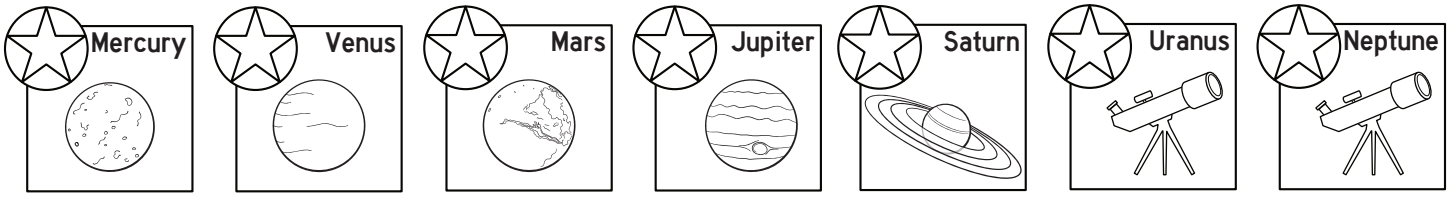
☐ Type 1 ☐ Type 2 ☐ Type 3

Draw an asterism or constellation you observed!

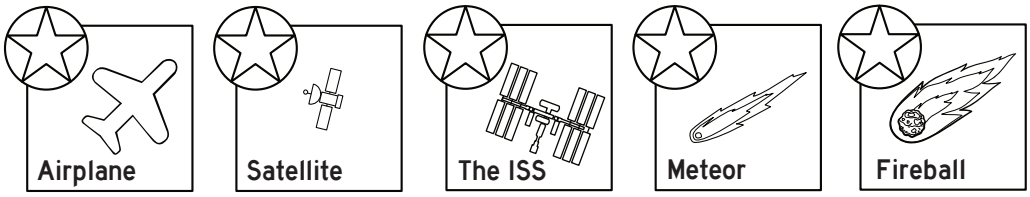
Stargazing Scavenger Hunt

Color in a star each time you observe one of the astronomical objects below! The telescope icon indicates objects that can only be seen with a telescope. *Note: not all objects will be visible at the same time!* Many constellations and stars are seasonal, only appearing at certain times of the year. Planets have periods of opposition where they are behind the Sun and not visible from Earth.

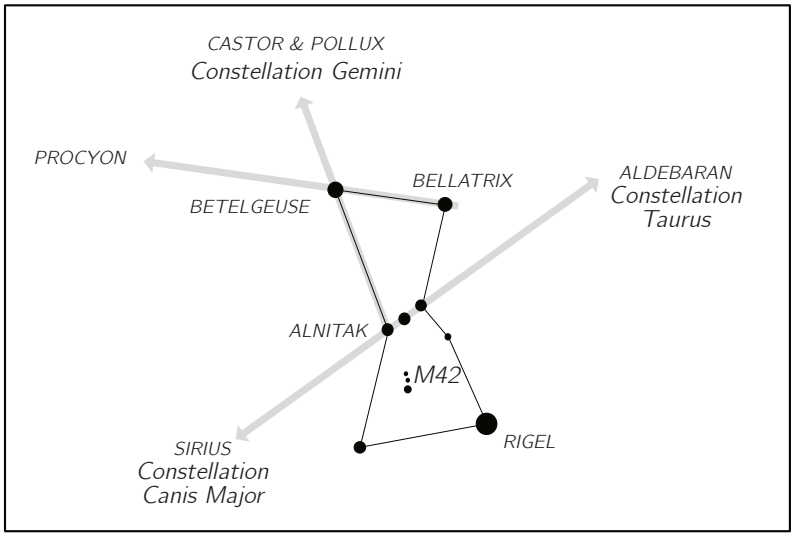
Planets:



Things that move fast in the sky:



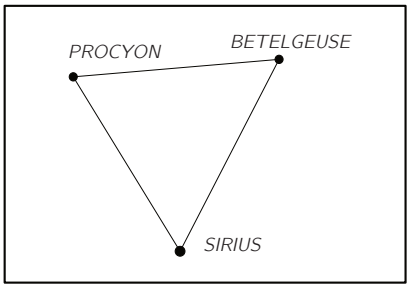
Orion and the Winter Triangle (also called the Great Southern Triangle)



Orion is best viewed from December through April. During this time of year it is visible from both the Northern and Southern Hemispheres.

Once you find Orion, you can use its stars to find Canis Minor, Canis Major, Gemini, and Taurus.

- **Identify Betelgeuse, Bellatrix, and Rigel**
  Can you see a color difference between these stars?
- **Use Bellatrix & Betelgeuse to find Procyon**
- **Use Orion's belt to find Sirius**
- **Can you see M42?**



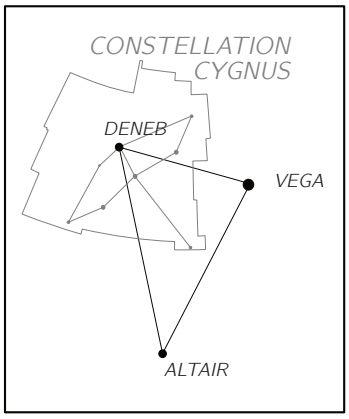
Three of the brightest stars in Orion, Canis Major, and Canis Minor form an asterism called the "Winter Triangle" or Great Southern Triangle.

- **Show someone else where the "Winter Triangle" is and identify each of the stars in that asterism.**

In 1781, the French astronomer Charles Messier published a list of 110 objects that were fuzzy in appearance. These were not stars and not comets – Messier was looking for comets and he began this list as a way of cataloging the "not a comet" objects that were frustrating his hunt. This Messier catalogue is arguably the most famous list of objects in space. Many of the nebulae and galaxies on the list are still referred to by their Messier catalogue numbers, like M42, the Orion Nebula.

Northern Hemisphere

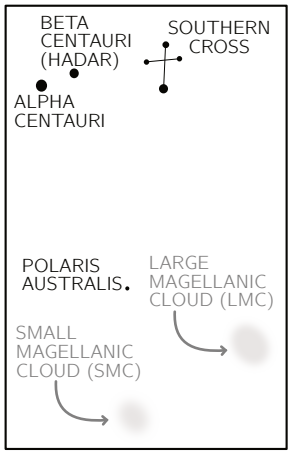
Can you find the following constellations or features?



- Summer Triangle
- Cygnus
- Ursa Major
- Polaris

Southern Hemisphere

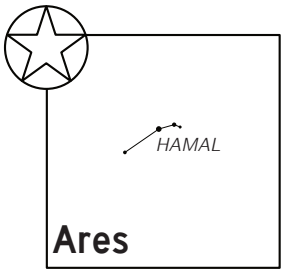
Can you find the following constellations or features?

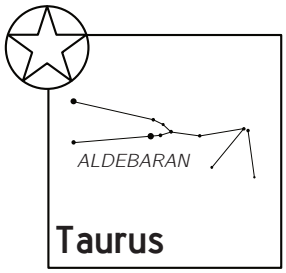


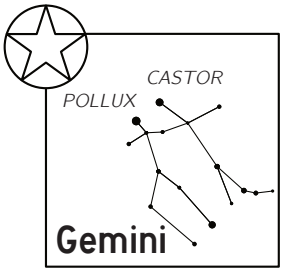
- Alpha Centauri
- Southern Cross
- Magellanic Clouds
- Polaris Australis

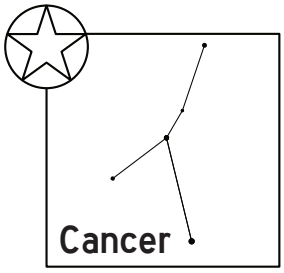
Constellations along the Ecliptic:

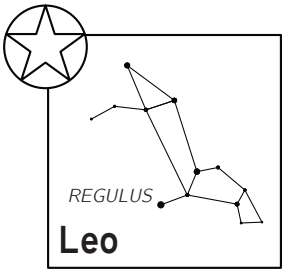
Famous or very bright stars are named.

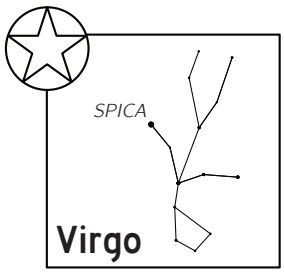


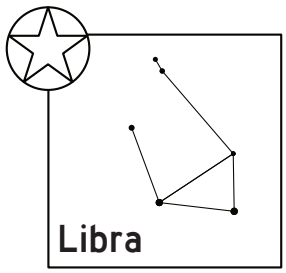


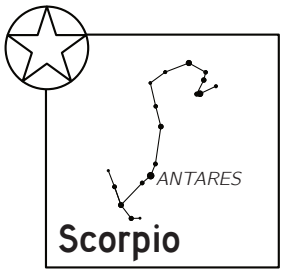


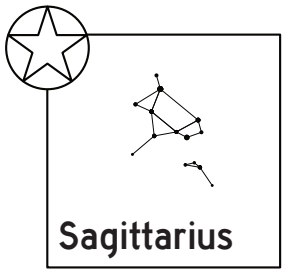


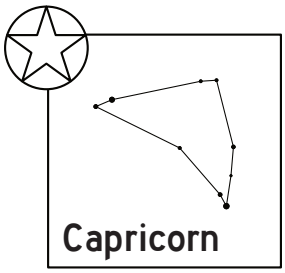


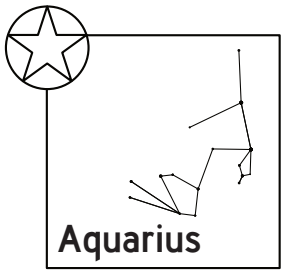


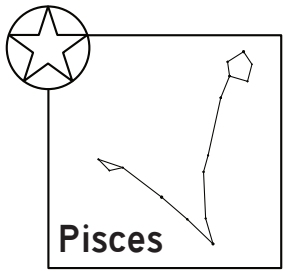


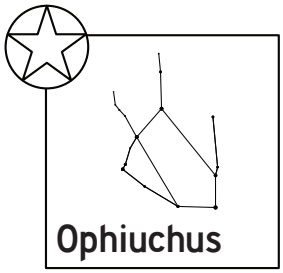




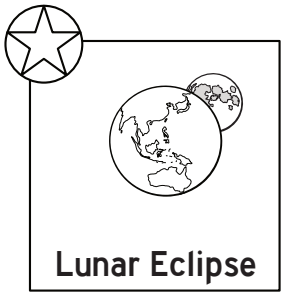


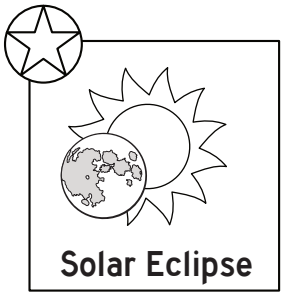


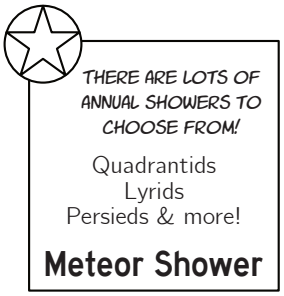


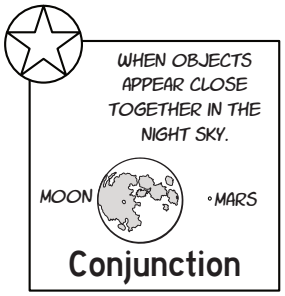


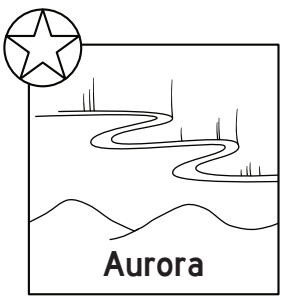
Exciting Events:



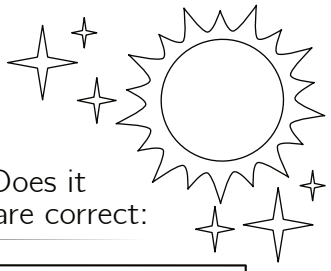








The Sun as a Star



The Sun contains more than 99% of the mass of the solar system.
Its gravity holds our solar system together and keeps the planets in their orbits.
The Sun is a star, but what exactly does that mean? What's the Sun made of? Does it rotate? Read the questions below and check the boxes by the answers you think are correct:

What is the Sun made of?	☐ *Fire*	☐ *Gas*	☑ *Plasma*	☐ *Something else*
Approximately how much larger is the Sun than Earth?	☐ *Same size as Earth*	☐ *10x wider*	☑ *100x wider*	☐ *1,000x wider*
Approximately how hot is the surface of the Sun? (Not the atmosphere)	☐ *600° Kelvin*	☑ *6,000° Kelvin*	☐ *600,000° Kelvin*	☐ *6,000,000° Kelvin*
Does the Sun spin? If yes, about how long does it take to rotate?	☐ *It doesn't rotate*	☐ *3 hours*	☐ *3 days*	☑ *30 days*
About how long does it take for light to travel from the Sun to the Earth?	☐ *8 seconds*	☑ *8 minutes*	☐ *8 hours*	☐ *8 days*

Characteristics of a star:

Size: Stars are objects so large their gravitational pressure causes FUSION.

Composition: Stars are mostly made of HYDROGEN and HELIUM.

Why they shine:

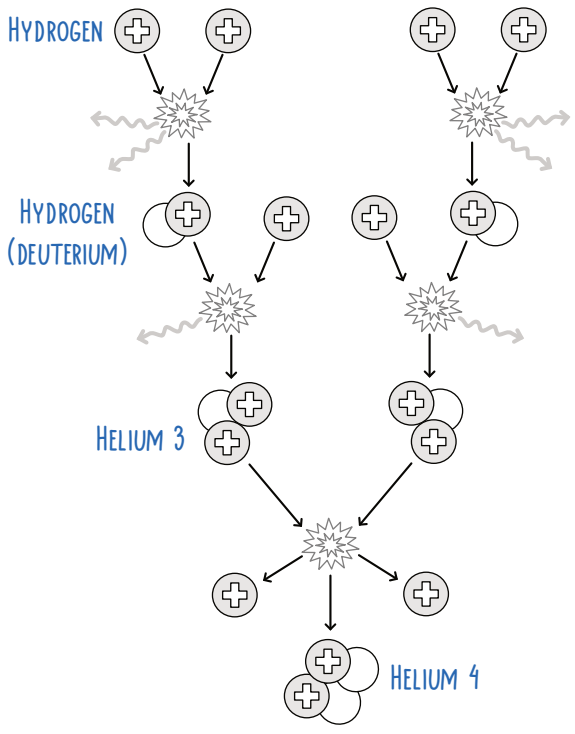
What powers stars? Why do they emit light?

STARS ARE LUMINOUS SPHERES OF PLASMA HELD TOGETHER BY THEIR OWN GRAVITY.

STARS ARE POWERED BY FUSION, WHERE THE NUCLEI OF ATOMS COMBINE TO FORM HEAVIER AND LARGER ELEMENTS.

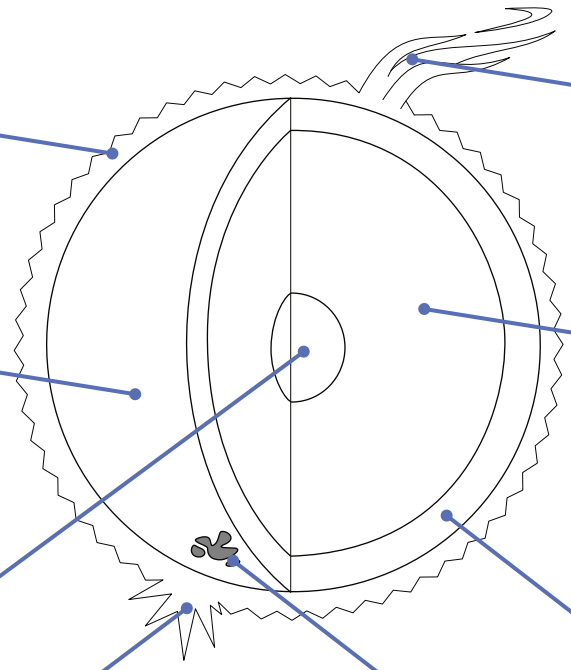
MOST OF OUR SUN IS HYDROGEN. BY MASS, THE SUN IS: 71% H, 27% HE, AND 2% OTHER HEAVIER ELEMENTS SUCH AS OXYGEN, CARBON, AND IRON.

FUSION PRODUCES RADIATION AND IS THE REASON THE SUN PRODUCES LIGHT AND HEAT.



Label the layers of the Sun

Label and draw lines to identify the following aspects of the Sun: convective zone, core, corona, coronal mass ejection (CME), flare, photosphere, radiative zone, sunspots.



The hot outermost layer of the atmosphere. Visible during total solar eclipses

CORONA

The visible "surface" of the Sun where most of the Sun's light is emitted. It's where we observe sunspots and flares

PHOTOSPHERE

The central region where nuclear fusion occurs. Generates intense heat and energy

CORE

An intense burst of radiation from the release of magnetic energy

FLARE

A large plume of plasma that erupts from the corona and travels through space

CORONAL MASS EJECTION (CME)

A dense layer where energy generated in the core is very slowly transferred outward

RADIATIVE ZONE

A turbulent layer where hotter plasma rises, cooler plasma sinks, and massive circular currents help transfer heat to the surface

CONVECTIVE ZONE

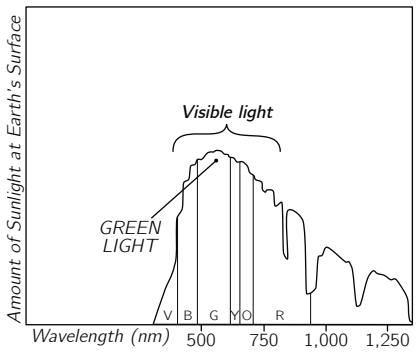
Dark cooler areas on the photosphere where magnetic field lines are concentrated

SUNSPOTS

Fact or Fiction?

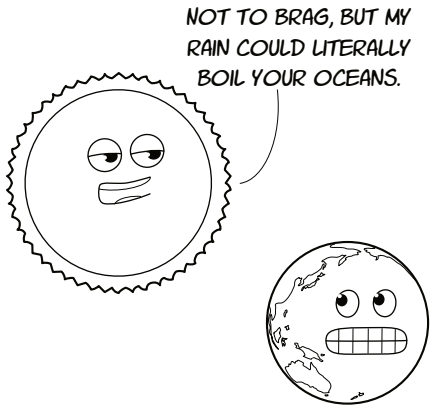
Consider each statement below. Is it fact or fiction?

The Sun produces more green light than any other wavelength of light



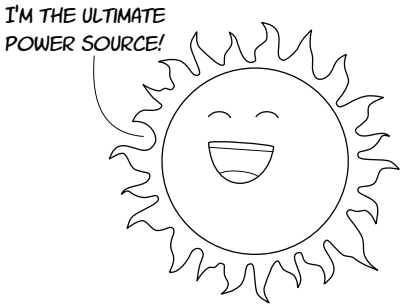
FACT. MANY STARS EMIT MOSTLY GREEN LIGHT. OUR SUN LOOKS WHITE TO US BECAUSE IT ALSO EMITS A LOT OF RED, ORANGE, YELLOW, AND BLUE LIGHT.

Sometimes it rains on the Sun



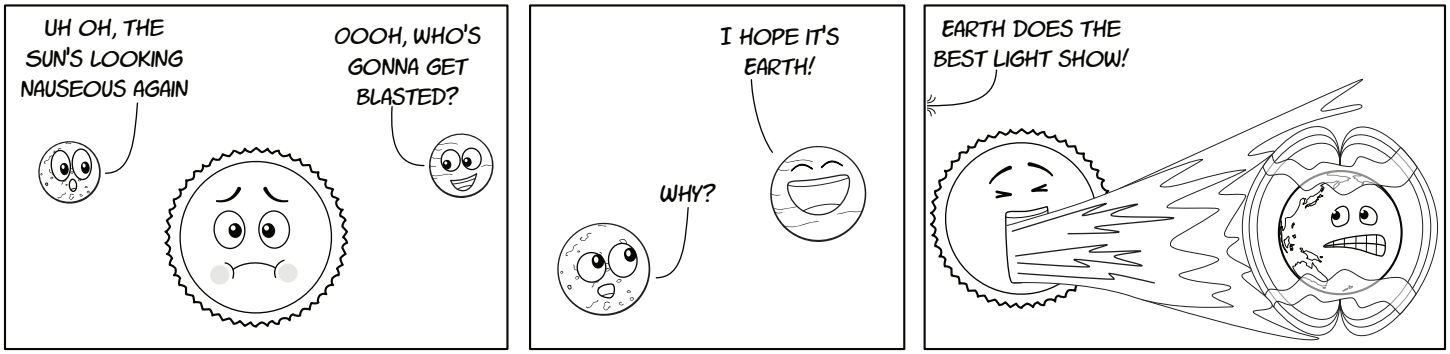
METAPHORICALLY, YES. WHEN HOT PLASMA MOVES IN A LOOP ALONG MAGNETIC FIELD LINES, IT COOLS AND CONDENSES, THEN FALLS TO THE SURFACE. THIS IS CALLED "CORONAL RAIN."

The Sun produces more energy in 2 seconds than humans have used in the last 1,000 years.



FACT. THE SUN PRODUCES ABOUT 3.8×10^{26} JOULES PER SECOND, WHICH IS AN ASTONISHINGLY LARGE NUMBER.

Solar Weather



Fill in the blanks

(words may be used more than once)

heliosphere *electrons* *wind* *particles* *solar* *energy* *second*

Some of the PARTICLES in the Sun's atmosphere have so much ENERGY, they escape the Sun's gravitational pull and travel into space. This stream of particles is called the SOLAR WIND. It's made mostly of ELECTRONS and protons, which travel between 400 to 800 kilometers per SECOND. The solar WIND extends beyond the orbit of Pluto, forming a large "bubble" called the HELIOSPHERE.

Match the Solar Phenomena with the Correct Definition

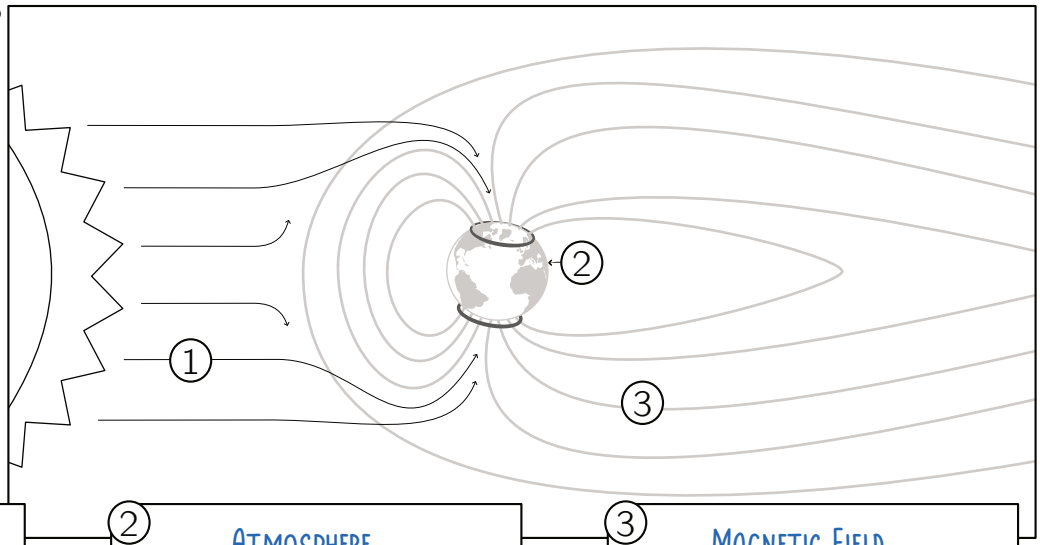
Prominence or Filament	Sunspot	Coronal Mass Ejection (CME)	Solar Flare	Coronal Loop
A massive amount of plasma is ejected from the Sun and thrown into space	A darker, cooler part of the Sun's surface	A bright structure of plasma extending into the Sun's atmosphere	An arc of plasma that flows along strong magnetic field lines	An eruption of high-energy radiation from the Sun's surface

What causes the auroras?

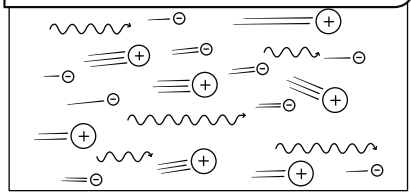
This diagram numbers the three qualities needed to produce auroras.

Label each of them in the boxes below. Then explain how they are involved in producing the colors of the aurora.

Is Earth the only planet with an aurora or do you expect to observe auroras on other planets too?

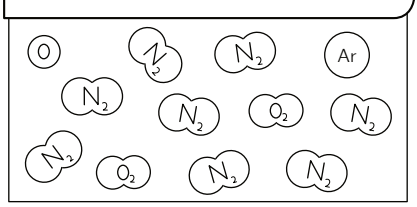


1 Solar Wind



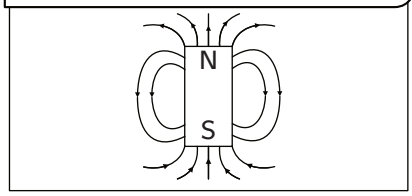
The solar wind provides the energy that powers the lights.

2 Atmosphere



Molecules absorb energy and then emit light. Color depends on element and altitude.

3 Magnetic Field



Funnels the solar wind to the poles and causes the "auroral oval" around N and S poles.

The Solar Cycle

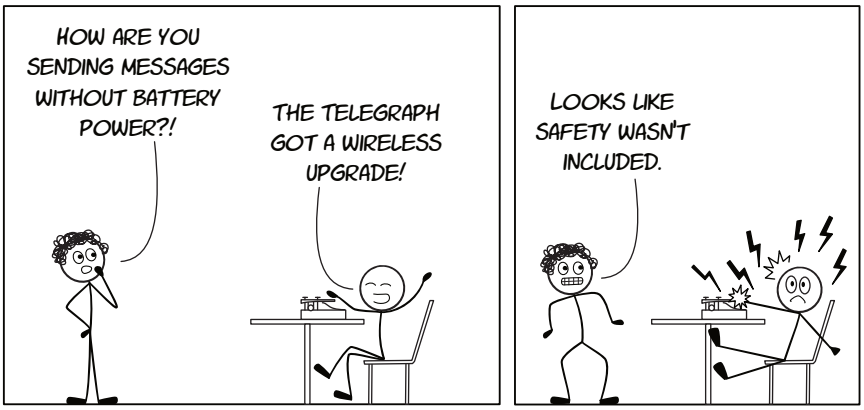
What is the Sun's solar cycle and how long does it take?

The solar cycle is an 11-year cycle in the Sun's activity. During a solar maximum, sunspots and all other activity such as CMEs and flares are much more abundant. During a solar minimum, sunspot activity is minimal. and the magnetic field lines of the Sun change direction. The cycle is measured by tracking the number of sunspots and fluctuates from minimum to maximum then back to minimum...

The Carrington Event

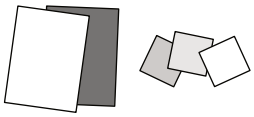
In 1859, scientists observed a bright flare. Seventeen hours later, Earth experienced the strongest geomagnetic storm ever recorded.

Strong aurora were visible globally. The storm caused telegraph lines to spark and if there had been more advanced technology, it would have been severely damaged by the storm.

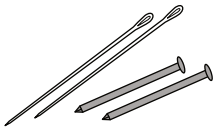


Solar Updraft Tower

MATERIALS

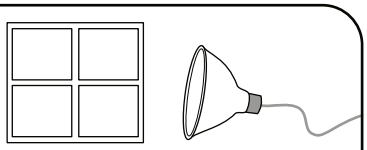


1 piece of black paper & 1 piece of white paper; smaller pieces of paper (any color)



2 nails OR
2 sewing needles

Thermometer

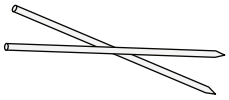


A sunny location OR an incandescent heat lamp

Scissors

Tape

Two small pieces of modeling clay



2 wooden skewers

Stopwatch (optional)

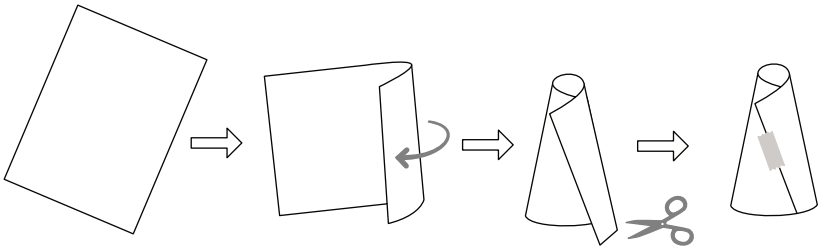
GOALS

- Learn more about solar energy and heat transfer
- Build a functional updraft tower

Instructions:

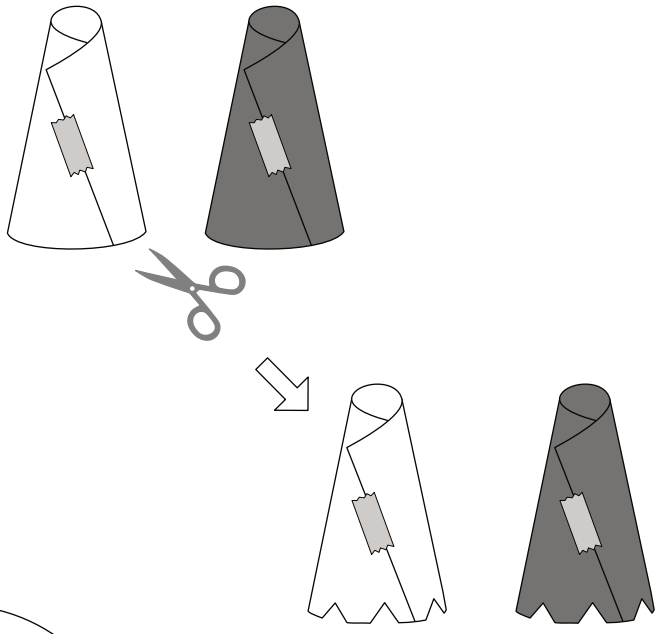
1. Make a paper "tower" by rolling the white piece of construction paper into a cone shape and securing it with tape.

The top of the tower should have a smaller diameter than the bottom. Fold the bottom or trim it with scissors so that the paper tower can stand upright on its own.



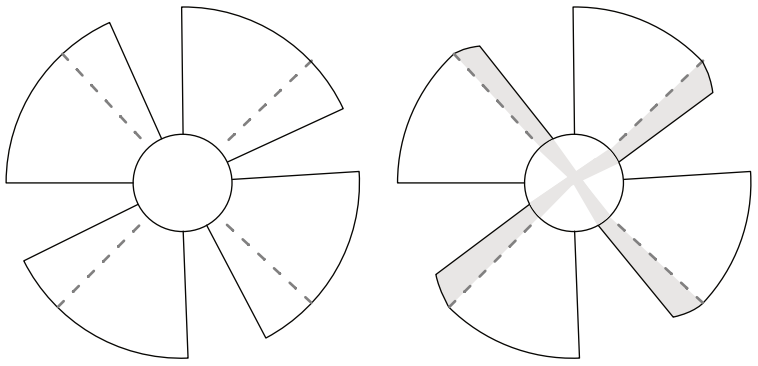
2. Make a second tower from the black piece of construction paper. Try to make it so the height and shape is the same as the white paper tower.

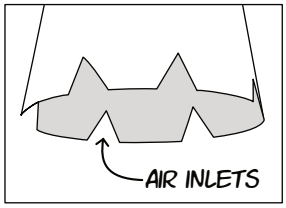
3. At the bottom of each paper tower, cut out 3 equally-spaced arches. These are the air inlets that will allow air to travel up into the tower.



4. Use scissors to cut 2 propellers out of the smaller pieces of paper. For best results, use a light paper (not construction paper or cardstock)

You can use the propeller template from the appendix or copy the design here:



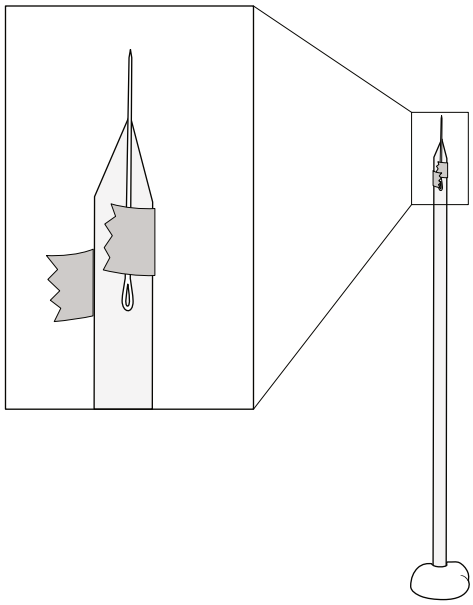


5. Tape one nail or sewing needle to the top of each of the wooden skewers. The propeller will sit on top of this point, resting on it so that it can turn easily.

6. Place each of the skewers into a piece of modeling clay so that they stand upright. Trim them, if needed, so they are not too much taller than the towers. Carefully set the tower over the skewer and then place the propeller on top.

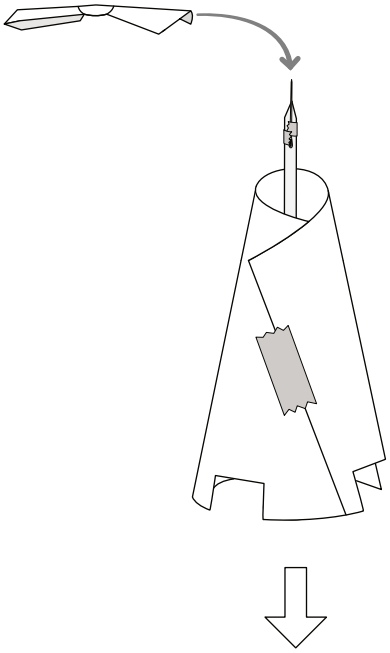
7. Measure the air temperature outside the tower and right above the tower and record it below.

8. Place both towers in bright sunlight or in front of a heat lamp for 5 minutes. Observe the towers. After 5 minutes, do another temperature measurement of the air inside and outside the towers.



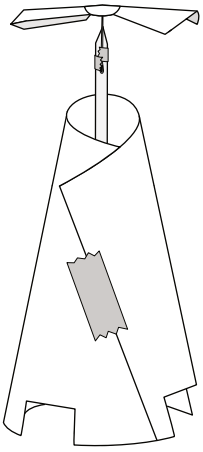
WHITE CONSTRUCTION PAPER

Temperature BEFORE bright light exposure	Temperature AFTER bright light exposure
Above tower:_____	Above tower:_____
Outside tower:_____	Outside tower:_____



BLACK CONSTRUCTION PAPER

Temperature BEFORE bright light exposure	Temperature AFTER bright light exposure
Above tower:_____	Above tower:_____
Outside tower:_____	Outside tower:_____



What did you observe:

_____

_____

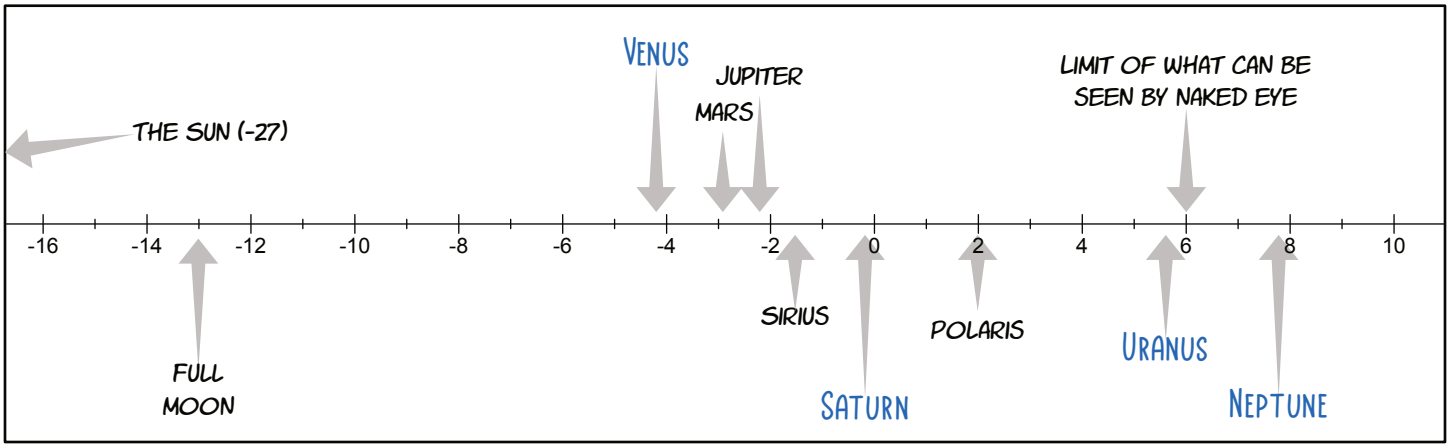
_____

_____

Main Sequence Stars

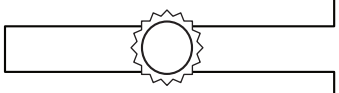
More than 2,000 years ago, the Greek astronomer Hipparchus invented a scale for measuring the brightness of stars. He gave the brightest stars the value of 1 and the dimmest stars the value of 6. This scale is the basis for how we measure brightness today–with some revisions to make it more mathematically sound. The brightness of Vega is designated to be magnitude 0. Then everything is scaled so an increase of 5 orders of magnitude corresponds to a 100× increase in brightness. Each step multiplies the brightness by: $\sqrt[5]{100}$ (≈ 2.51)

Fill in Neptune, Saturn, Uranus, and Venus on the magnitude scale below. Remember, *the **brighter** an object appears, the **lower** its magnitude.*

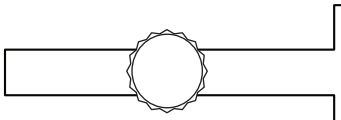


What is the difference between magnitude and luminosity?

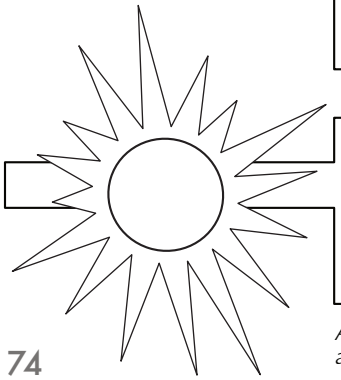
LUMINOSITY MEASURES THE AMOUNT OF ELECTROMAGNETIC ENERGY EMITTED OVER TIME. IT DOES NOT CHANGE WITH DISTANCE. APPARENT MAGNITUDE IS A MEASURE OF HOW BRIGHT A STAR APPEARS FROM EARTH. CLOSER STARS APPEAR BRIGHTER THAN DISTANT STARS. ABSOLUTE MAGNITUDE IS HOW BRIGHT A STAR WOULD APPEAR FROM 10 PARSECS (~32 LY) AWAY.



Sol (the Sun)
Mass: 1 M
Luminosity: 1 L
Apparent Magnitude: -26.7
Absolute magnitude: 4.83



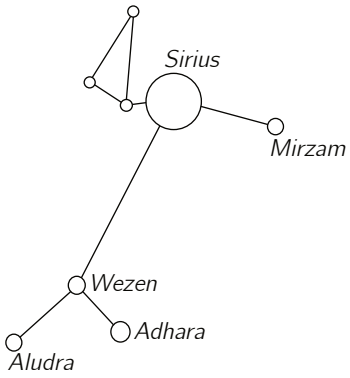
Sirius A
Mass: 2.06 M
Luminosity: ~25 L
Apparent Magnitude: -1.46
Absolute magnitude: 1.43



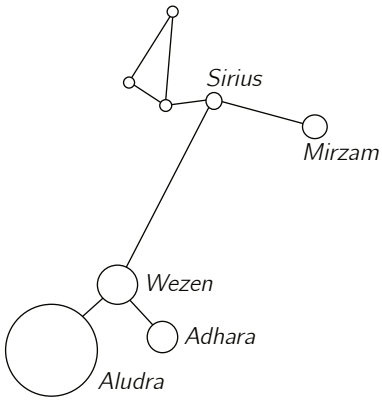
Aludra
Mass: 5.5-9.5 M
Luminosity: ~163,000 L
Apparent Magnitude: 2.4
Absolute magnitude: -7

Absolute magnitude: how bright the star would appear if exactly 10 light years away

*Apparent **magnitude** of stars in Canis Major*



***Luminosity** of stars in Canis Major*

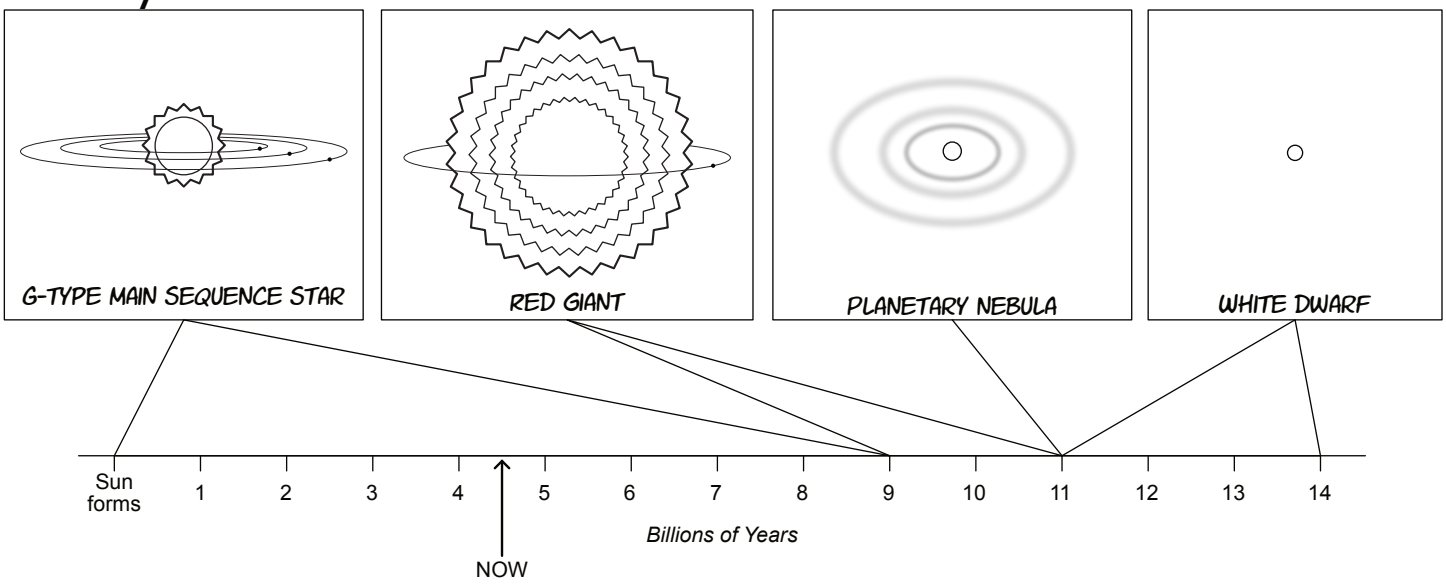


Fill in the blanks
(words may be used more than once)

expand	*explode*	*hydrogen*	*main*	*mass*	*sequence*	*shrink*

Most stars in the known universe are in a category called the MAIN SEQUENCE . These stars will use HYDROGEN as fuel and fuse it into helium. When they run out of fuel, what happens next depends on the MASS of the star. Small stars SHRINK and cool down. Medium-mass stars EXPAND into red giants and then collapse into white dwarfs. And high-mass stars become supergiants and then EXPLODE .

The fiery future of our Sun



What is the Sun's fuel as a main sequence star? Is its size stable? Why or why not?

THE SUN'S FUEL IS HYDROGEN. ITS SIZE IS STABLE AS LONG AS IT HAS HYDROGEN TO BURN – THE FORCE OF GRAVITY PULLING INWARD IS BALANCED BY THE OUTWARD FORCE OF HEAT FROM FUSION.

What is the Sun's fuel as a red giant? Is its size stable? Why or why not?

THE SUN BEGINS HELIUM FUSION, CREATING CARBON AND OXYGEN. PRESSURE FROM THE CORE CAUSES THE SUN TO EXPAND DRAMATICALLY. MERCURY AND VENUS WILL BE CONSUMED BY THE SUN AND LIKELY EARTH AS WELL.

Why is the term planetary nebula misleading?

IT IS NOT WHERE PLANETS ARE FORMED! A PLANETARY NEBULA IS AN EXPANDING CLOUD OF GAS PRODUCED BY AN AGING STAR. IT DOESN'T LAST LONG COMPARED TO THE OTHER PHASES.

Describe the Sun during its white dwarf phase:

IT WILL BE MADE OF CARBON AND OXYGEN AND SUPER DENSE. IT WILL GLOW BRIGHTLY AS IT GIVES OFF HEAT FOR BILLIONS OF YEARS, BUT IT IS NOT UNDERGOING FUSION ANY LONGER. EVENTUALLY IT WILL COOL DOWN.

Supernova!

Stars change and evolve over their lifetime. What happens in each stage largely depends on the star's size. Describe each phase of a star's life cycle below:

low-mass star
Red Dwarf
ex. Proxima Centauri
0.1 $M_\odot$

Old Age: Blue dwarf

Red dwarfs are the most common, smallest, coolest, and longest-lived stars in the universe. When they exhaust the hydrogen in their cores, they burn hotter and brighter (appearing blue)

Death: After fusion stops, they just shrink

They aren't large enough to fuse helium into carbon and oxygen, so when all the hydrogen in the outer layers is used up they shrink in size, becoming either white dwarfs or brown dwarfs.

Remnant: White dwarf or brown dwarf

Most red dwarfs would become white dwarfs – but the process is so slow (trillions of years) we haven't observed it. Very small red dwarfs would (in theory) become brown dwarfs and then black dwarfs

medium-mass star
Yellow Dwarf
ex. the Sun
1 $M_\odot$

Old Age: Red Giant

These stars expand dramatically when they run out of hydrogen for fusion in their cores. Eventually they will contract and fuse heavier elements like oxygen and carbon.

Death: Planetary Nebula

The outer layers are ejected into space to form a halo called a planetary nebula (misnomer).

There is no more fusion in the core (which will become the remnant)

Remnant: White dwarf

The white dwarf is a super-dense sphere of carbon and oxygen that shines super brightly because of how hot it is. Fusion no longer takes place.

high-mass star
Blue Supergiant
ex. Rigel
17-24 $M_\odot$

Old Age: SuperGiant

The most massive stars burn bright and fast. Some only last for a few million years. Supergiants are the largest stars in the universe.

Death: Type II Supernova!

When these stars use up all of their fuel, the outward heat and pressure of fusion no longer counteracts the inward pull of gravity and the star collapses and then explodes in a supernova.

What type of remnant forms depends on the size and composition of the star.

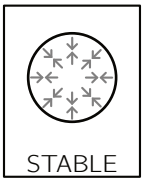
Remnant option 1: Neutron star

If the core is between 1.4 and 3 solar masses, it forms a neutron star.

Remnant option 2: Black Hole

If the core is greater than 3 solar masses, it forms a black hole.

Describe the pressures acting on stars that are stable in size, expanding, or shrinking:



STABLE

Outward heat and pressure from fusion = inward pull from gravity.

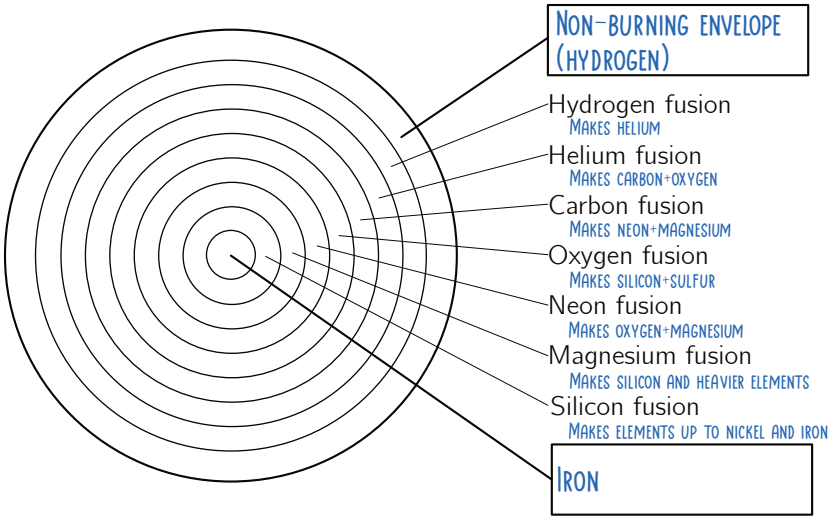
EXPANDING

Pressure from fusion is greater than inward pull from gravity.

SHRINKING

Pressure from fusion is smaller than inward pull from gravity.

Before going supernova, stars develop an onion-like structure:



What element(s) are being made in the Sun?

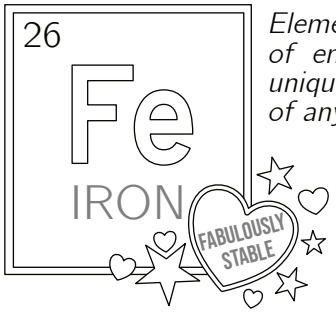
Helium. That's it for now. (In its red giant phase it will make other elements)

What element(s) are being made in the red giant star Betelgeuse?

Mostly helium, carbon, oxygen, neon, magnesium, silicon, sulfur, and iron. Iron (26th element) is the heaviest element made.

What element(s) could be made when Betelgeuse goes supernova?

Many more! Elements from carbon (6th element) to rubidium (37th element)



Elements lighter than iron emit large amounts of energy when fused. Iron does not. It's unique because it has the most stable nucleus of any element.

Elements heavier than iron can only be made through neutron capture (a very slow process) or during the actual explosion of a supernova.

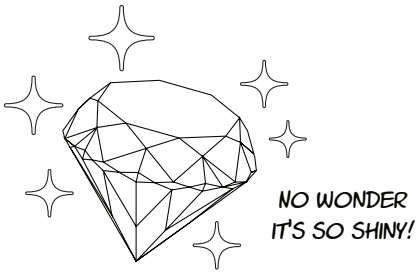
Every atom in your body came from a star that exploded. The atoms in your left hand probably came from a different star than your right hand. It's the most poetic thing in all of physics: You are stardust.

-Lawrence Krauss

Fill in the fabulous facts:

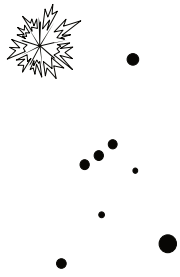
Consider each statement below. Is it fact or fiction?

A white dwarf star is an Earth-size diamond



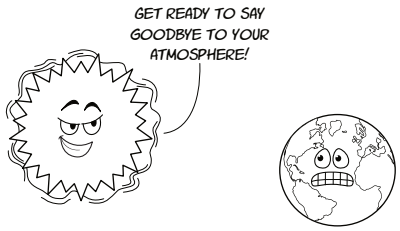
Fiction, but element of truth: The degenerate material in a white dwarf is mostly carbon, but it's much more dense than a traditional diamond.

Betelgeuse could have already exploded, we just haven't seen it yet.



Fact: The red giant is more than 400 light years from Earth. Whenever we see the supernova, we'll know it actually happened more than 400 years ago.

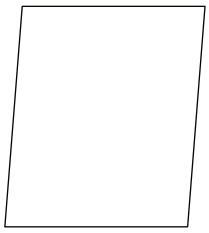
If a supernova occurred 250 ly from Earth, it would wipe out all life on our planet



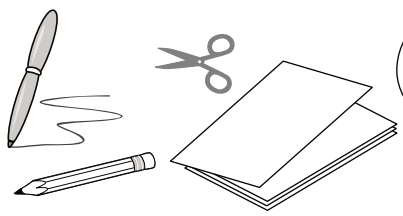
Fiction: But near-Earth supernovae are dangerous. Ones 25 ly away can destroy the ozone layer. It's possible the Ordovician and Devonian extinctions were caused by a near-Earth supernova.

Star Classification Poster

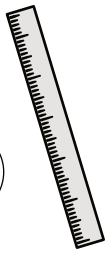
MATERIALS



A large piece of paper, cardboard, or poster board



Material to make the star diagrams. For 2-D models, use coloring supplies and paper. For 3-D models, use balloons or papier-mâché to create spheres or hemispheres



A ruler

GOALS

- Learn how stars are classified
- Recognize that stellar properties like size, luminosity, and temperature are interconnected.
- Strengthen ability to interpret visual data.

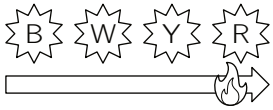
All stars are large spheroids of burning plasma. But how hot are they? How large are they? What types of radiation do they produce? As you'll discover putting this poster or chart together, there is a lot of variety!

Before making your star classification, make two predictions. Then fill in the the following page.

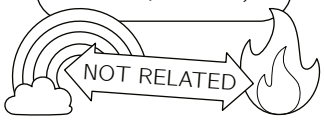
Before plotting the stars, make 2 predictions:

1. Are color and temperature related? If so, what do you think the relationship is? Choose one of the following predictions. Then write a sentence or two that explains your reasoning for your prediction.

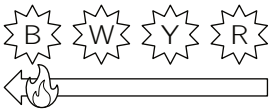
Red stars are hotter than blue stars



No correlation
(color is not related to temperature)



Blue stars are hotter than red stars



A different prediction
(describe it below!)

My prediction and why I made it: _____

_____

_____

_____

2. Are the brightest stars the closest stars? Why or why not?

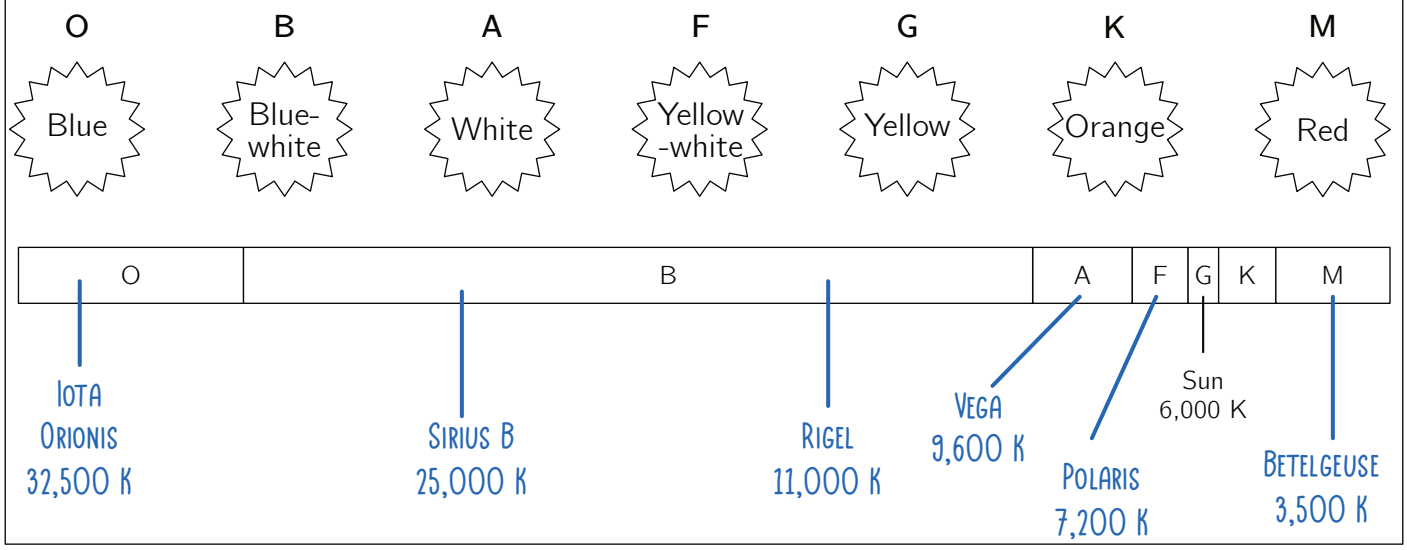
_____

_____

_____

_____

SPECTRAL CLASS



Choose a star from each spectral class from the table on the next page. Label its name and temperature in the spectral class box above. The Sun has been filled in as an example.

Note that the spectral class is arranged from blue (O) to red (M). Which color of star is the hottest?

BLUE stars are the hottest and RED are the coolest!

Red dwarfs are the most common star in the universe! 75% of the stars in the Milky Way are red dwarfs.

Here are 5 mnemonic devices to help remember the order of the different spectral types. Draw a picture of your favorite!

- *Owls Build Amazing Forts Guarding King Mice*
- *Old Bananas Are Fuzzy, Gross, Kinda Mushy*
- *Only Brave Astronauts Fight Giant Krakens*
- *Our Big Alien Found Giant Kale Muffins*
- *Oh Be A Fine Guy/Gal, Kiss Me*

Favorite OBAFGKM Mnemonic:

"Each substance sends out its own vibrations of particular wavelengths, which may be likened to singing its own song."

-Annie Jump Cannon

Making the Poster

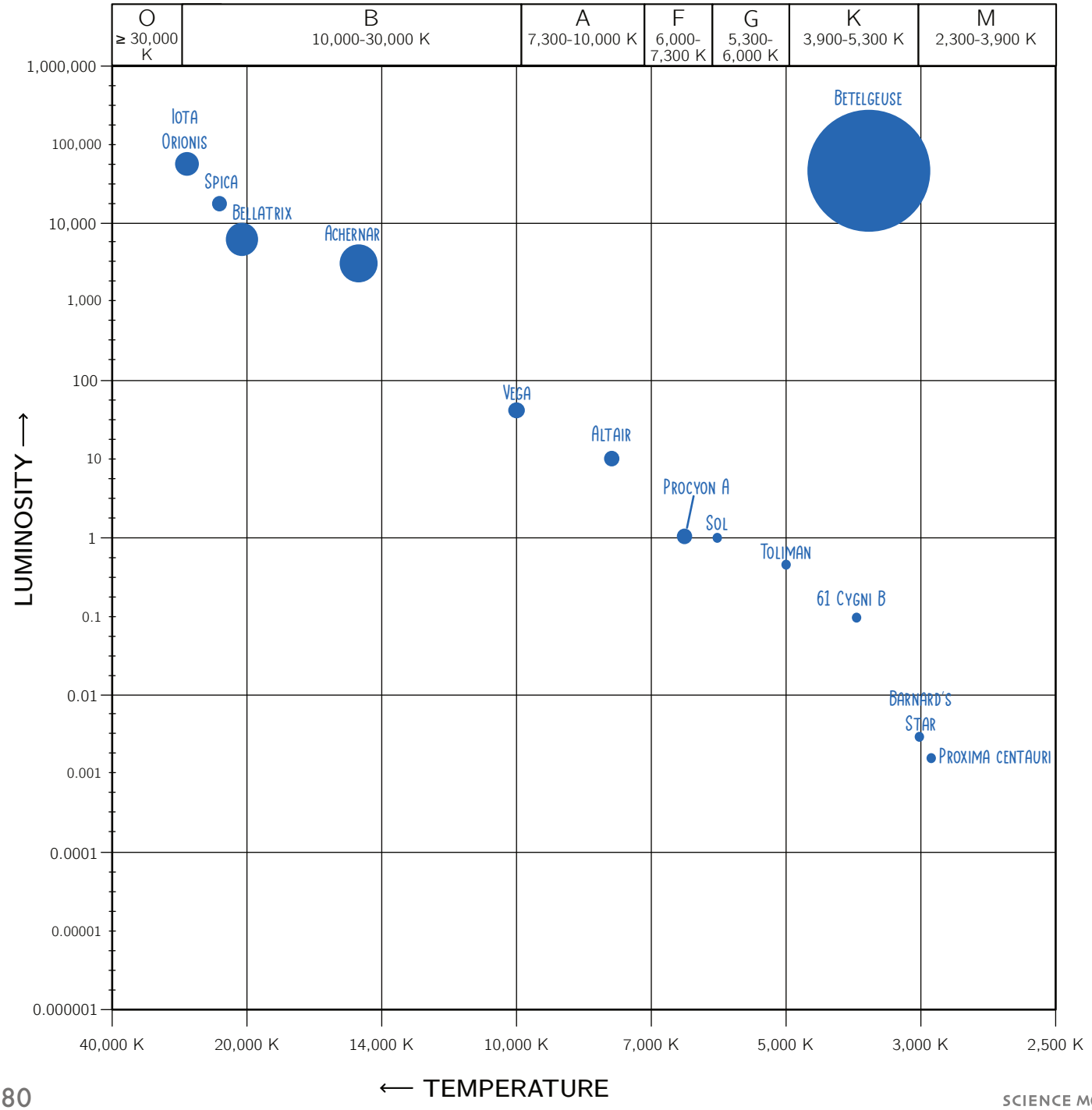
1. Create a large square area for the poster using cardboard, posterboard, or paper.

2. Create a grid with 7 columns and 6 rows. Use a ruler to ensure they are evenly spaced. This will become your Hertzsprung-Russell diagram.

3. Label the vertical axis for **luminosity**, which is the total amount of electromagnetic energy emitted per unit of time. It's measured based on the Sun. Our star (the Sun) has a luminosity of 1. The luminosity axis should be labeled from 0.000001 to 1,000,000.

4. Label the horizontal axis for **temperature** in Kelvin with the highest temperature (40,000 K) being on the left of the axis and the coolest temperature (2,500 K) being on the right.

5. Create models of your stars! The models can be flat (made of paper or cardboard) or they can be 3-dimensional and made of hemispheres or balloons that are inflated to different levels.



Stars to plot on your H-R Diagram:

Star	Distance from Earth	Size (solar radius)	Luminosity (bolometric)	Surface Temperature in Kelvin	Dominant Color	Spectral Class
Altair *Constellation Aquila*	*17 ly*	*2*	*11*	*8,000 K*	White	*A*
Achernar *Constellation Eridanus*	*140 ly*	*8*	*3,500*	*15,000 K*	Blue-white	*B*
Barnard's Star *Constellation Ophiuchus*	*6 ly*	*0.2*	*0.003*	*3,000 K*	Red	*M*
Bellatrix *Constellation Orion*	*250 ly*	*6*	*7,500*	*22,000 K*	Blue-white	*B*
Betelgeuse *Constellation Orion*	*550 ly*	*700*	*87,100*	*3,600 K*	Red	*M*
Toliman (α Centauri B) *Constellation Centaurus*	*4.3 ly*	*0.9*	*0.5*	*5,000 K*	Orange	*K*
61 Cygni B *Constellation Cygnus*	*11 ly*	*0.6*	*0.1*	*4,100*	Orange	*K*
Iota Orionis *Constellation Orion*	*1,300 ly*	*8*	*68,000*	*32,500 K*	Blue	*O*
Procyon A *Constellation Canis Minor*	*11 ly*	*2*	*7*	*6,600 K*	Yellow-white	*F*
Proxima Centauri *Constellation Centaurus*	*4.2 ly*	*0.15*	*0.0016*	*2,900 K*	Red	*M*
Sol *Our Solar System*	*0.00001 ly*	*1*	*1*	*5,800 K*	Yellow	*G*
Spica *Constellation Virgo*	*250 ly*	*7.5*	*20,300*	*25,000 K*	Blue-white	*B*
Vega *Constellation Lyra*	*25 ly*	*2.7*	*47*	*10,000 K*	White	*A*

Values in the above chart are approximate!

Star temperature, size, and distance are often reported with a range of values (for example, Achernar has a luminosity of 3,493 +/- 429, and the star Bellatrix has a temperature between 21,700 and 22,941 K. We rounded values to make the chart cleaner and easier to use.

After plotting your stars, what trends do you notice?

Most stars fall along a diagonal pattern. The hottest stars are the most luminous to the brightest.

Cooler stars are red and more dim (less luminous)

Compared to the other stars, what is unusual about Betelgeuse?

Betelgeuse is WAY larger than any other stars! It is also unusually cool for how bright it is (or we could say that it's unusually bright for its temperature.)

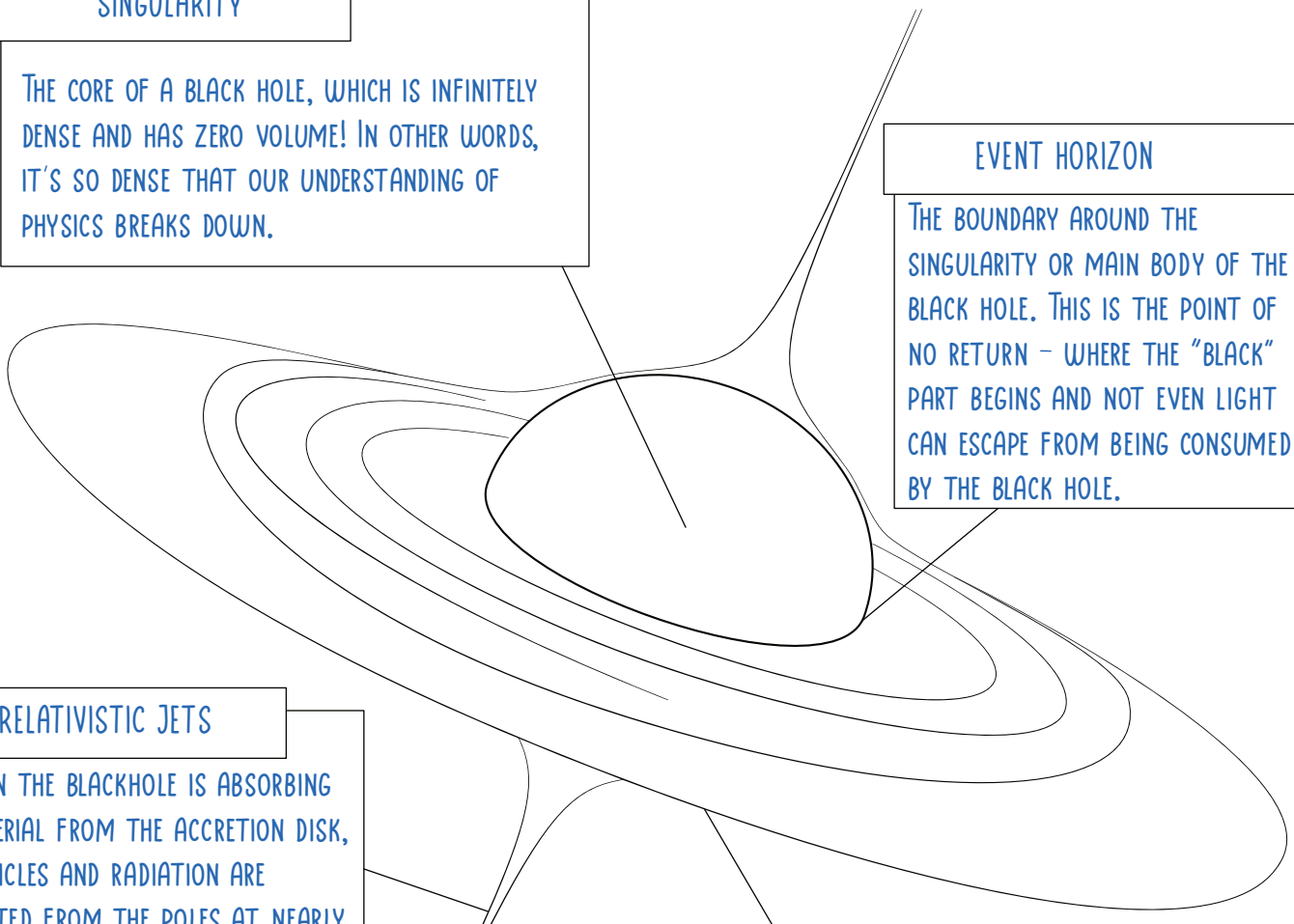
Black Holes

Fill in the blanks
(words may be used more than once)

collapse	holes	light	matter	singularity	space	stars	supernova

Black holes are not actually HOLES . They are huge concentrations of MATTER packed into a very small SPACE . Their gravitational pull is so strong that not even LIGHT can escape. Black holes are usually formed after STARS explode in a SUPERNOVA . If the core of a dying star is more than 3x the mass of the Sun, it will COLLAPSE until it reaches a point of infinite density called a SINGULARITY .

Features of a Black Hole
Label and describe the following: singularity, event horizon, relativistic jets, accretion disk



SINGULARITY

The core of a black hole, which is infinitely dense and has zero volume! In other words, it's so dense that our understanding of physics breaks down.

EVENT HORIZON

The boundary around the singularity or main body of the black hole. This is the point of no return - where the "black" part begins and not even light can escape from being consumed by the black hole.

RELATIVISTIC JETS

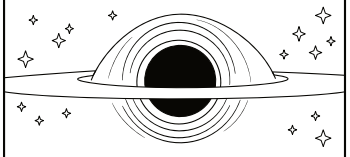
When the blackhole is absorbing material from the accretion disk, particles and radiation are blasted from the poles at nearly the speed of light.

ACCRETION DISK

Superheated gas and dust orbiting the black hole, it releases electromagnetic radiation (esp x-rays).

Match each object with the correct description

Supermassive black hole	Intermediate mass black hole	Stellar-mass black hole	Primordial black hole

10 - 100,000 $M_\odot$	3 - 50 $M_\odot$		>100,000 $M_\odot$
			
Black holes with a mass 100 to 100,000 times larger than the Sun. Likely formed when smaller black holes merge.	Formed during the supernova of a star at least 20x larger than the Sun. This type of black hole is often found near another star.	Believed to have formed at the beginning of the universe. Could exist in a wide variety of sizes. Not yet confirmed.	Almost every large galaxy has one of these black holes. The one at the center of our galaxy (Sagittarius A*) is 4 million times more massive than the Sun!

Cygnus X-1

The first black hole discovered! The name "Cygnus X-1" means it was the source of the brightest X-rays within the constellation Cygnus. It's a binary system with a blue supergiant star and a black hole (Cyg X-1) orbiting each other.

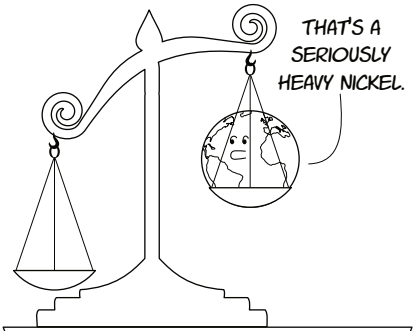
It's a stellar-mass black hole formed after the collapse of a star. It's pulling matter from the supergiant star next to it. Some of the matter is absorbed and some is ejected. It's spinning very fast!

Fact or Fiction? *Consider each statement, then write whether it is fact or fiction.*

If the Sun was replaced by a black hole that had the same mass, Earth's orbit would remain unchanged.

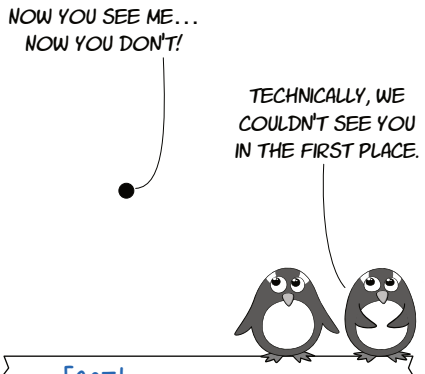
FACT! The gravitational pull of a black with a similar mass.

A black hole the size of a nickel would have a mass greater than the Earth



FACT!

All black holes are slowly evaporating



FACT!

Galaxies & Our Local Neighborhood

Match the definition with the correct term and fill in the typical range of the number of stars:

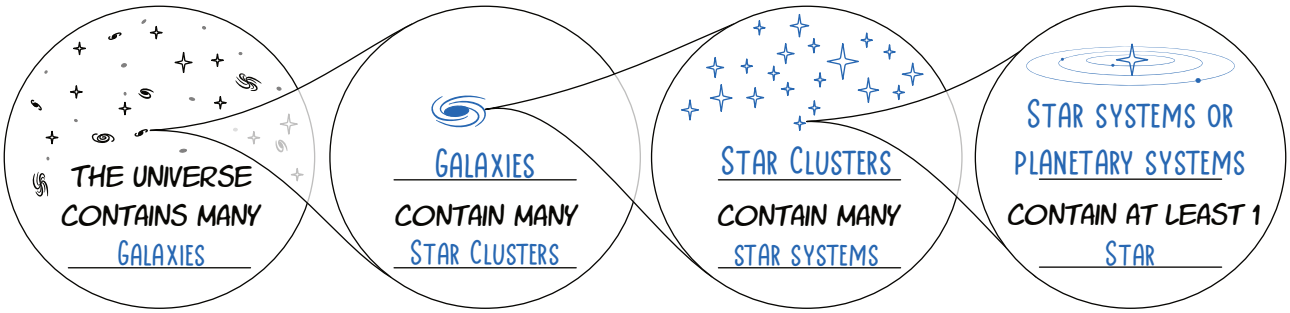
	Galaxy	Star System	Star Cluster	Universe
	A group of non-stellar objects that revolve around a star or multiple stars	A large group of stars, dust, and gas held together by gravity and dark matter	A group of stars bound together by gravity, stars tend to be of similar age	Everything that exists; all of the matter and energy we know of
# of stars:	1-7 STARS	BILLIONS TO TRILLIONS	DOZENS TO MILLIONS	~10^{24} STARS

(OPEN CLUSTERS HAVE DOZENS TO HUNDREDS OF STARS, GLOBULAR CLUSTERS ARE MUCH LARGER)

Fill in the blanks

(words may be used more than once or not at all)

galaxies | *planetary system* | *star system* | *star cluster* | *solar system* | *universe*



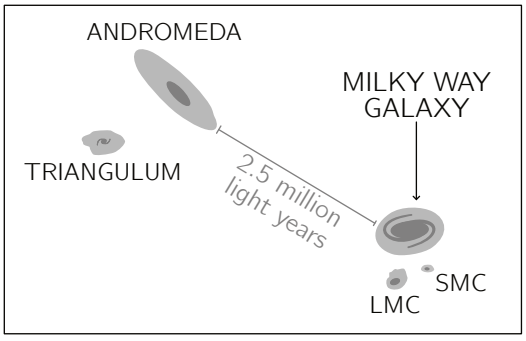
Our Galaxy: The Milky Way

How did it get its name?

FROM THE APPEARANCE OF THE "MILKY" BAND OF LIGHT WE SEE WHEN LOOKING AT THE ARM/SIDE OF THE GALAXY

What type of galaxy and how many stars?

SPIRAL. 100-400 BILLION - AND AT LEAST THAT MANY PLANETS TOO!

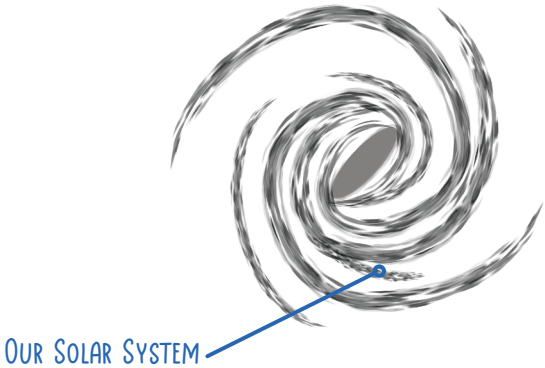


Where is Earth in the Milky Way?

ON THE ORION SPUR

What is at the center of our galaxy?

SAGITTARIUS A* WHICH IS A SUPERMASSIVE BLACK HOLE



Our Nearest Neighbor: The Alpha Centauri System

Take notes! Write down your favorite facts here:

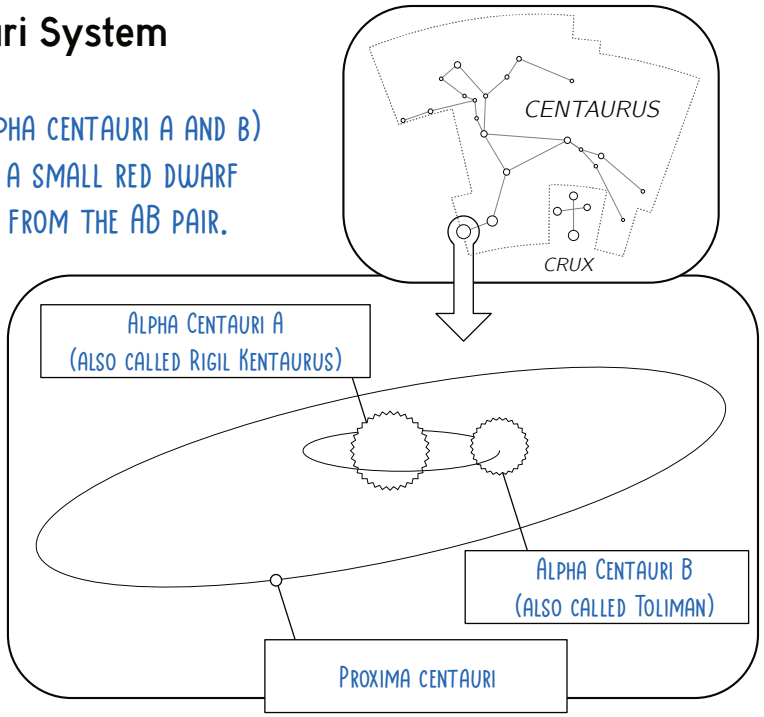
This triple star system contains 2 sun-like stars (Alpha Centauri A and B) that orbit fairly close to each other. Further away is a small red dwarf called Proxima Centauri that orbits about 12,000 AU from the AB pair.

Proxima Centauri is 4.25 light years from Earth.

Proxima Centauri has 2 confirmed planets.

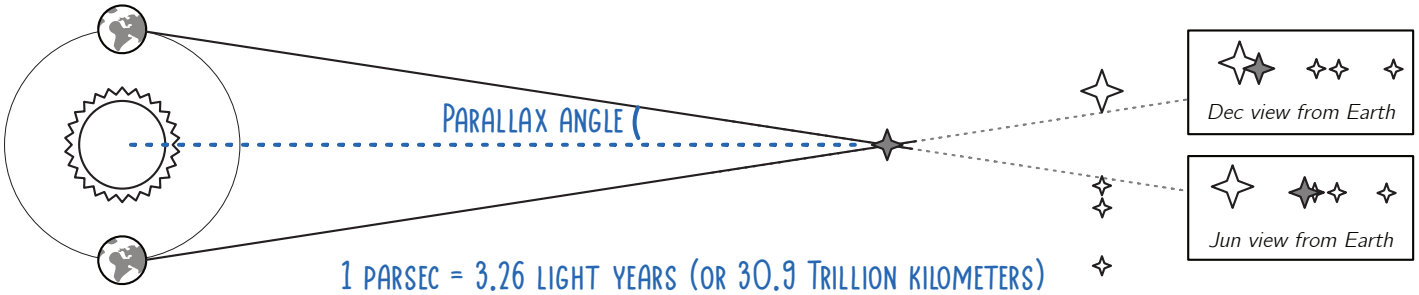
This star system is the 3rd brightest star in Earth's night sky (Sirius is the brightest, then Canopus, then Alpha Centauri (The triple star system looks like a single star from Earth).

Centaurus is near the constellation Crux.



How far away?

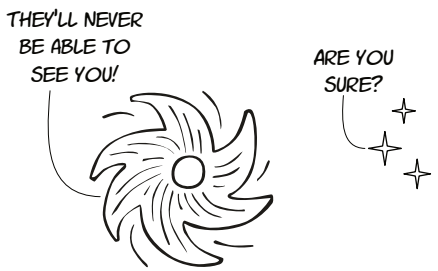
The position of a star can appear to shift depending on where Earth is in its orbit. This angle of change or parallax angle is measured in arcseconds, which are incredibly small (3,600 arcseconds to equal 1°). A **parsec** is the distance to an object with a parallax angle of 1 arcsecond.



1 parsec = 3.26 light years (or 30.9 Trillion kilometers)

Fact or Fiction? *Consider each statement, then write whether it is fact or fiction.*

Every star you can see without telescopes is a star from the Milky Way Galaxy



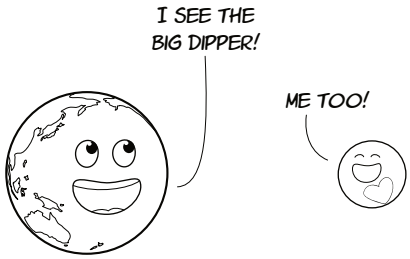
Fact! You can see some galaxies from Earth (such as Andromeda or the Magellanic clouds) but you can't see individual stars within those galaxies.

If the Sun were the size of a grain of sand, the Milky Way would be as wide as the continental United States.

Fiction! The Milky Way would be as wide as the Earth to the Moon distance, assuming one grain of sand is 0.5 mm in diameter.

$$\underbrace{100,000\ \text{ly}}_{\text{M.W. diameter}} \cdot \underbrace{\frac{9.5 \cdot 10^{15}\ \text{m}}{1\ \text{ly}}}_{1\ \text{ly} = 9.5 \cdot 10^{15}\ \text{m}} \cdot \underbrace{\frac{0.0005\ \text{m}}{1\ \text{Sun}}}_{\text{scale factor}} \cdot \underbrace{\frac{1\ \text{Sun}}{1.3927 \cdot 10^{9}\ \text{m}}}_{\text{Sun diameter}} = 341,064\ \text{km}$$

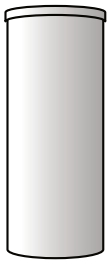
The major constellations and asterisms appear the same from Pluto as from Earth.

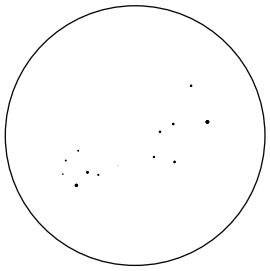


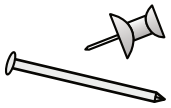
Fact! Pluto and the Earth are so close together compared to the distant stars in constellations, it's like looking at a distant mountain after taking one step to one side. The view doesn't change.

Constellation Viewer

MATERIALS


Cardboard cylinder (such as a Pringles can)


Constellation Handout


Nail or pin


Scissors

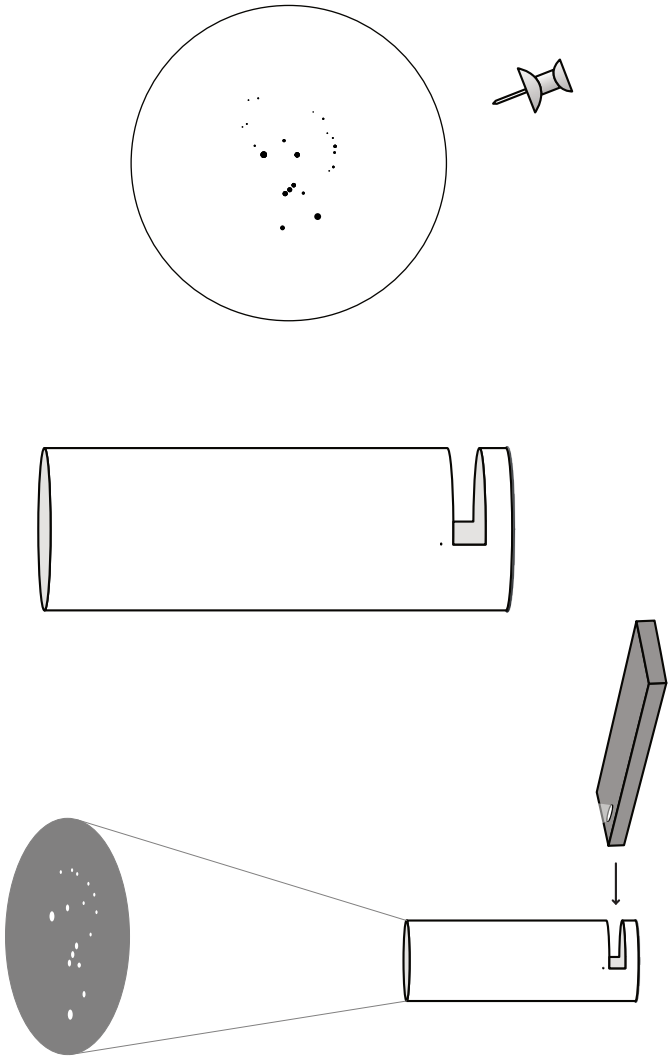

Phone with flashlight

GOALS

- Learn the constellations used to navigate and mark the seasons
- Engineer a device to project constellations; develop testing and troubleshooting skills

Make a Constellation Viewer

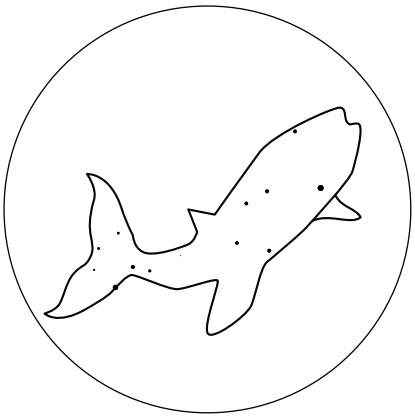
1. Cut out the circles of the 18 constellations from the appendix.
2. (Optional) Tape or glue the constellation circle to thin cardboard so the projection disk is sturdier.
3. Use a thumb tack and/or nail to poke holes in the dots of the constellation. It will be easiest and safest to place the disk on a few layers of cardboard while poking the holes.
4. Cut a 1 cm slit in the side of the cylindrical tube or Pringles can. The cut portion should be near the bottom edge and be wide enough for the phone flashlight to be placed inside the can.
5. Place the constellation slide into the clear can lid or place it in front of the tube.
6. Locate a dark room with a lightly-colored wall.
7. Place the phone in the can with the flashlight on and shine it on the constellation card. If things are lined up neatly, star projections should appear on the wall. Try several distances to get the optimal projection.

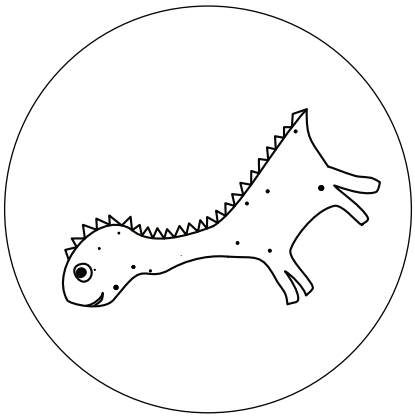


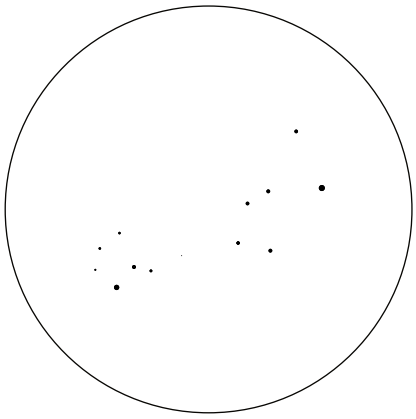
Turn the constellation card upside down or sideways. It's harder to recognize when it isn't oriented how we expect! Reference objects in the night sky can be very helpful in recognizing and finding constellations. Once you get familiar with one constellation in the night sky, you can use it to find other nearby constellations.

Constellation Art Activity

Using your creativity to make a picture from a collection of stars can help you better recognize that pattern in the future. Print off one of the pages of constellations and invent your own legend and name for that constellation. Be as creative as you want! Below are two samples of Cetus the Sea Monster.







A New Constellation

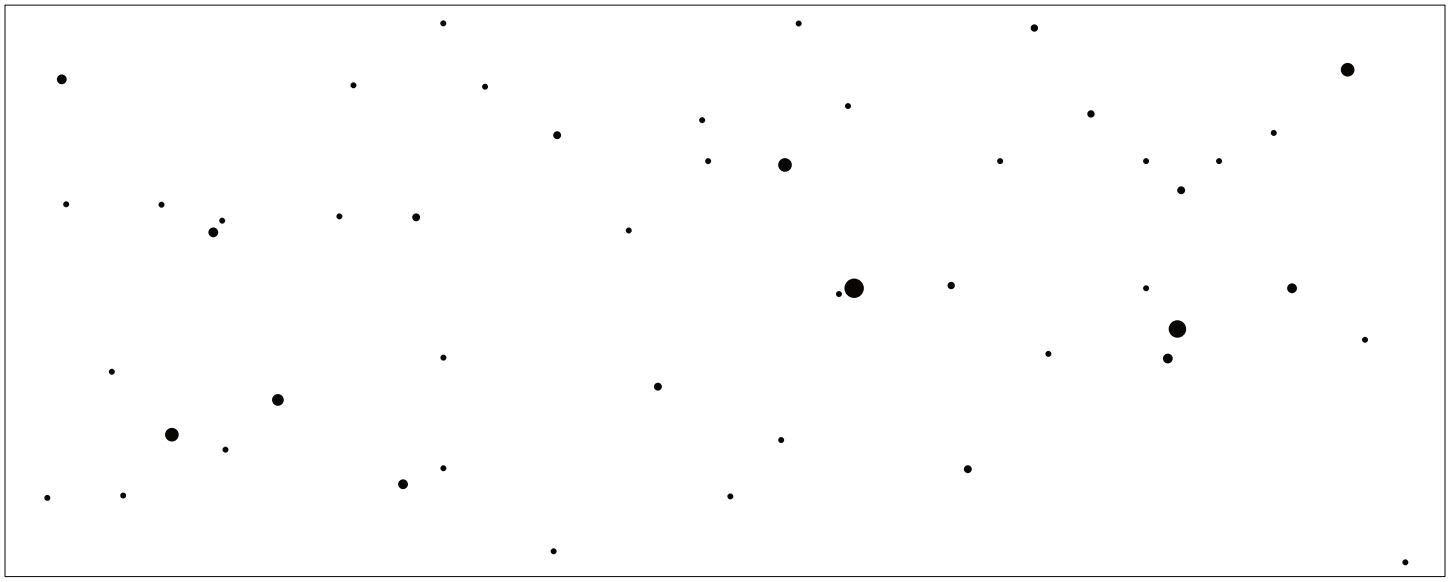
The constellations are Earth-based constructions with rich histories. Would an astronaut on Mars find the same constellations in the Martian sky? Explain.

Yes. The constellations will look almost identical from Mars. It's like looking at a distant mountain and taking a step to the side; the mountain will still look the same.

Would an astronaut on a planet on the other side of the Milky Way Galaxy see the same constellations? Explain.

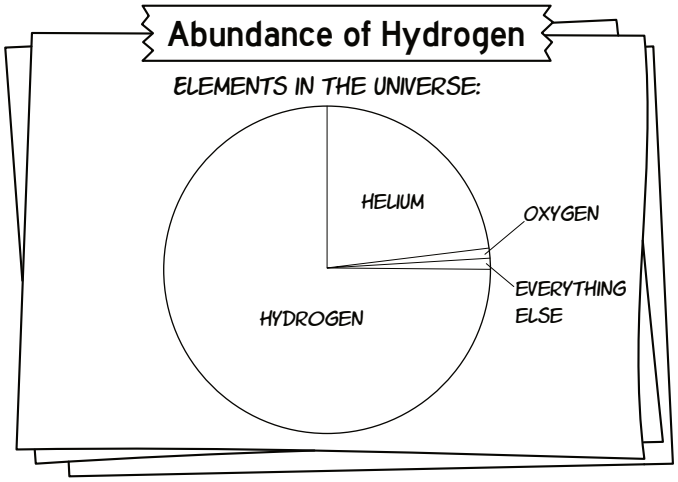
On the other side of the galaxy, the constellationsn will be entirely different. This is more like traveling around to the far side of the mountain and looking back.

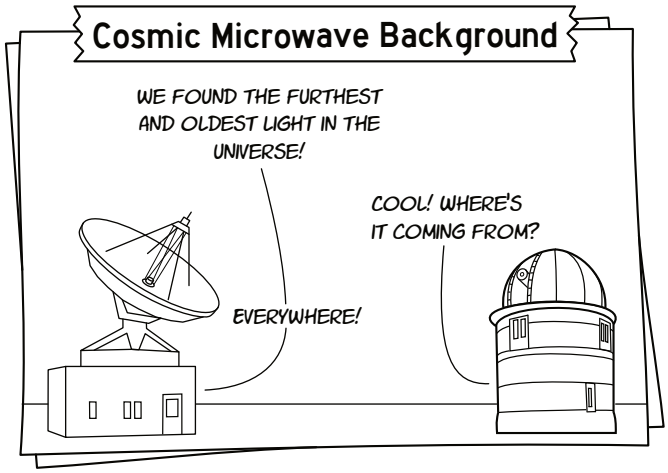
Below is a made-up star pattern making up a swath of the sky that is 30° wide. Subdivide this star pattern into constellations and give them names.

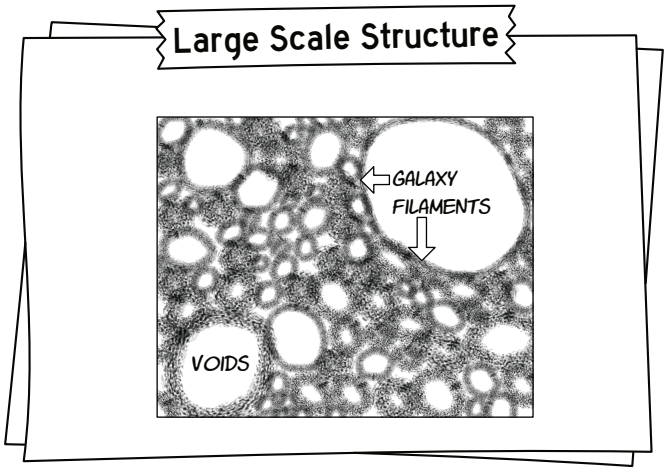


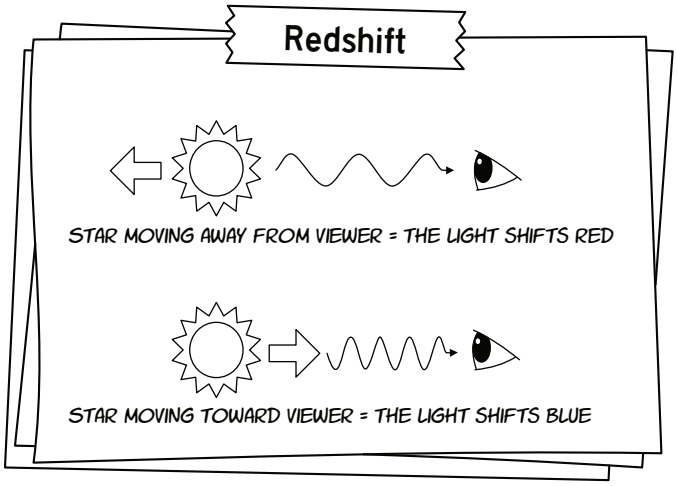
Spacetime and the Universe

When we look at our known universe, there are a few key characteristics that are especially significant. Look at each in turn and then ask yourself "What would explain this?" Then record how each relates to our current understanding of the formation of the universe.









Abundance of hydrogen:

The universe was dense plasma that cooled and formed atomic nuclei. Big Bang models based on physics and nuclear reaction rates predict the universe should be about: 75% hydrogen & 25% helium

Cosmic Microwave background:

Cosmic microwave background (CMB) is the afterglow of the Big Bang. It's faint, uniform radiation detected in all directions and fits with what's expected from a hot, expanding universe.

Large Scale Structures

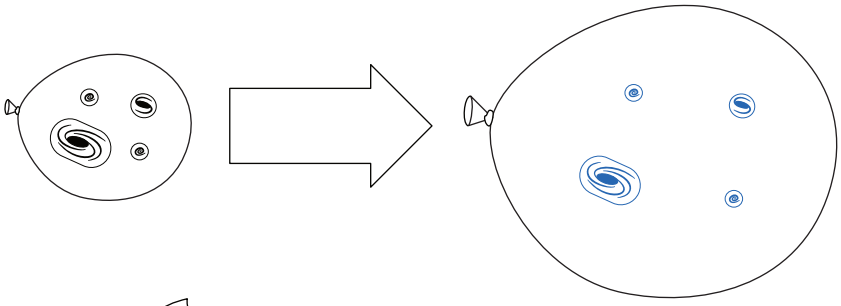
The distribution of galaxy clusters across the universe shows patterns (filaments, walls, voids) that formed as small density variations from the Big Bang grew under gravity.

Redshift / Hubble's Law:

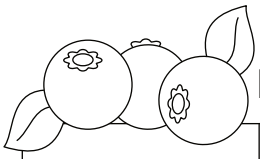
Galaxies are moving away from us which redshifts their light (wavelengths stretched). This supports the expanding universe, a central prediction of the Big Bang.

Expanding universe:

A partially-inflated balloon has galaxy stickers on the surface. What will happen to the distances between galaxies as the balloon is inflated so that it has twice the diameter? Draw the galaxies on the fully inflated balloon below.



Cool fact: In our expanding universe the distances between galaxies expand but the size of galaxies does not because they are gravitationally bound together.



Blueberry Model of the Galaxy

	Actual distance	Distance in blueberry scale
Diameter of Sun	$1.4 \cdot 10^6$ km	1 cm
Distance to Proxima Centauri	$4.02 \cdot 10^{13}$ km	$2.87 \cdot 10^7$ cm or 287 km
Diameter of Milky Way Galaxy	$9.4 \cdot 10^{17}$ km	$6.71 \cdot 10^{11}$ cm or 6.7 million km
Thickness of spiral arms	$9.5 \cdot 10^{15}$ km	$6.78 \cdot 10^3$ cm or 67,800 km

If the Sun was scaled to the size of a blueberry, could you make an accurate model of the Milky Way Galaxy out of fruit? Assume a diameter of 1cm for the Sun. Then convert the other values to the same scale.

How much space would you need to make this model? Would it be possible to make?

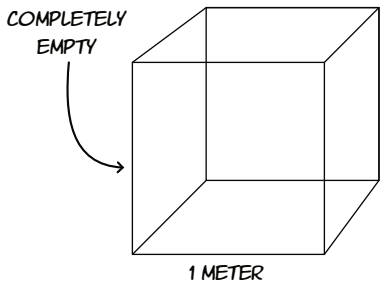
The model would be 6.7 million kilometers wide – that's more than 16 times further than the Earth-Moon distance!

The thinnest part (the spiral arms) would be 67,800 km tall (The atmosphere is about 10,000 km tall).

If you were holding the blueberry that represented the Sun, the nearest star would be 287 km away.

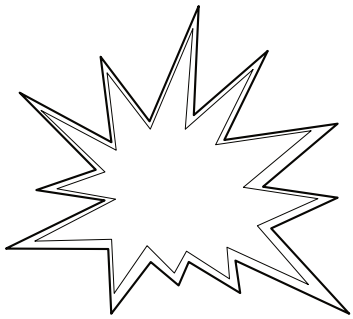
Fact or Fiction?

Space is a total vacuum. A cubic meter of space doesn't contain a single atom.



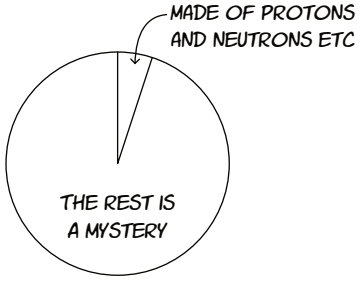
Fiction! The interstellar medium has approx. 1 atom per cubic meter. It's closer to a total vacuum than any vacuum we can make on Earth, but there's still matter.

The big bang theory states that the universe exploded out of nothing.



Fiction! The Big Bang theory states that about 14 billion years ago the universe was in a state that was much warmer and much denser than it is now.

Only 5% of the universe is made of matter we can observe



Fact! The mysterious missing mass that makes up most of the universe (95% of it) is called dark matter.

Dark Matter

Fill in the blanks

(words may be used more than once or not at all)

invisible	*light*	*gravity*	*absorb*	*interact*	*80%*	*50%*	*5%*

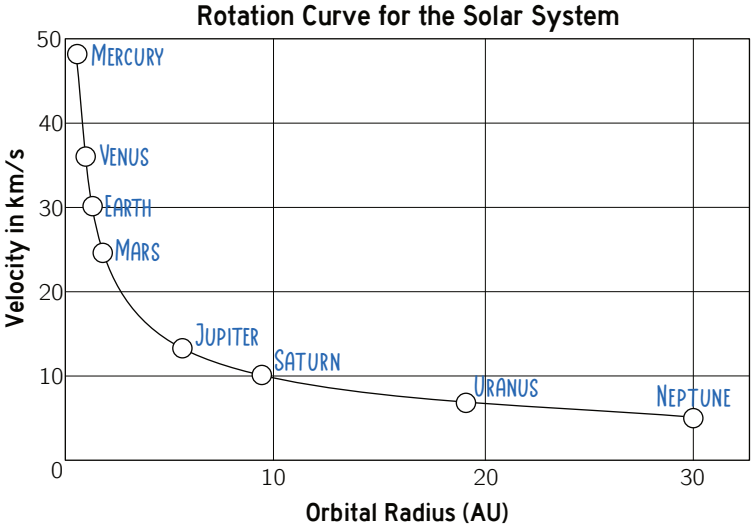
Visible matter only accounts for **5%** of the known universe. The rest is made of "dark" matter or energy, meaning it does not **ABSORB**, reflect or emit **LIGHT**. Since dark matter does not **INTERACT** at all with the electromagnetic force, it is **INVISIBLE**. Evidence for its existence comes from how its **GRAVITY** affects visible matter.

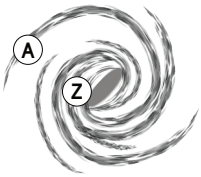
Galaxy Rotation Curves

Kepler's laws of motion describe how orbiting matter behaves. Objects further away from the center of mass move slower than those close to the center.

Plotting planet velocity by distance gives us a rotation curve for the solar system.

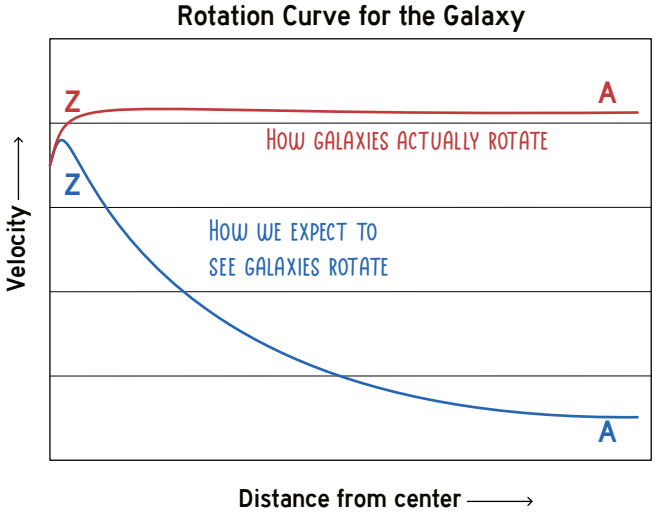
Label the 8 planets featured in the graph below:



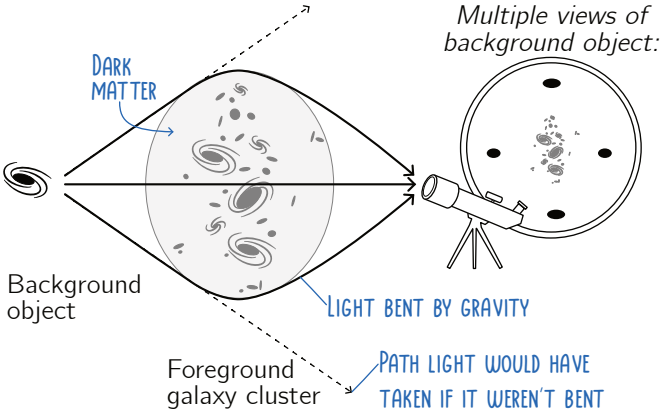


Galaxies also rotate. What would you expect the rotation curve of a galaxy to look like? Would material at point A move faster or slower than material at point Z?

Plot what you'd expect to see in a rotation curve for a galaxy:



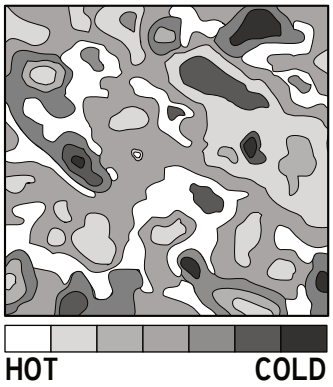
Gravitational Lensing



Describe how this happens:

GRAVITATIONAL LENSING OCCURS WHEN A MASSIVE FOREGROUND OBJECT WARPS THE SPACE AROUND IT, BENDING THE LIGHT. THIS DISTORTS THE IMAGE OF THE BACKGROUND OBJECT INTO RINGS, ARCS OR MULTIPLE POINTS OF LIGHT.

Cosmic Microwave Background



The Cosmic Microwave Background (CMB) is filled with hot and cold spots. When scientists look at how much the temperature fluctuates at different scales (very large patches vs very small patches), they get a graph that shows how matter was condensing in the early universe.

This graph (the CMB power spectrum) does not fit what would happen if the universe only contained visible matter. Visible matter interacts with photons but dark matter does not. In the early universe, the pressure from photons would have kept ordinary matter from forming deep gravity wells. It would have resulted in much weaker hot and cold spots in the CMB.

A universe with more dark matter than ordinary matter explains the patterns we see in the CMB.

The top evidence for dark matter:

Summarize them in your own words!

1. Galaxies rotate too fast for the amount of visible matter they contain.
2. Light bends more than expected around distant objects.
3. Cosmic Microwave Background patterns fit a model with both dark and visible matter.

Could all of these be caused by something else?

There have been and are other theories such as Modified Newtonian Dynamics, but the issue is that none of them explain all 3 phenomena. The Lambda Cold Dark Model (ΛCDM model) is the best fit for our current data and the most widely accepted cosmological model.

Doodle Challenge
Create a wanted poster for a dark matter particle!

Artwork and description will vary! Hopefully the description will say something about the particle not being visible.

A few fun ideas:

"Mysterious suspect adding mass to galaxies without showing up in photos. Last seen bending light"

"Cold, slow-moving particle wanted for shaping the cosmic web. Case unsolved since the Big Bang."

"Wanted: ultimate hide and seek champion. This particle has been hiding in plain sight spread across the entire universe. Reward offered for first detection!"

"Suspect is invisible and doesn't interact with light. Leaves only gravitational footprints."

"Wanted: whatever is causing the dark matter phenomena. Whether it's MACHOs, WIMPs, axions, or entirely new particles!"

Stars, Galaxies, and Universe Review

IN YOUR OWN WORDS!

Learning and understanding new words is an important part of astronomy! Define each of the following terms in your own words. If the word has a box, use that space to draw and label a diagram.

CORONA: The outermost layer of the Sun, only visible during a total solar eclipse. Temperatures here can reach over 2,000,000°F (1,000,000°C).

FUSION: The reaction in which two or more atomic nuclei combine. In the process, one or more new nuclei will be created. Ex: 2 hydrogen atoms fuse to form a helium atom.

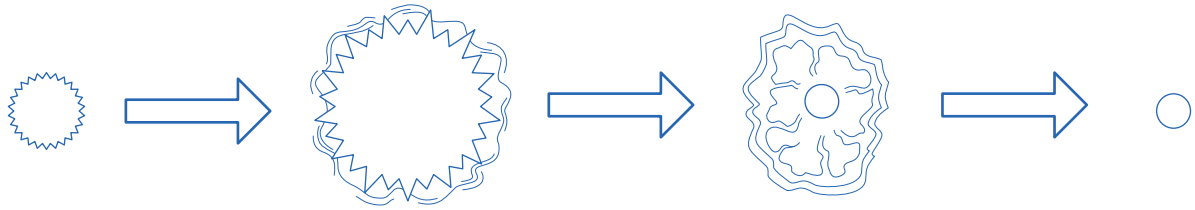
LIGHT YEAR: The unit of distance measuring how far light travels in one Earth year. It is equivalent to 5.88 trillion miles (9.46 trillion km). The speed of light in outer space is 299,792,458 meters per second.

GALAXY: A group of thousands of stars, gas, and dust held together by gravity.

BLACK HOLE: A region in outer space where gravity is so extreme that even light cannot escape. At the center is a single point with infinite density called a singularity.

SUPERNOVA: The explosion when a massive star collapses at the end of its life. The incredible amount of energy released can even outshine a galaxy.

MAIN SEQUENCE STAR:



The young main sequence star is fusing hydrogen into helium.

When the star runs out of hydrogen it expands into a red giant.

Outer layers are blown off and become a planetary nebula. Fusion no longer happens in the remaining core, which is now a white dwarf.

The core is now a white dwarf made mostly of very dense carbon and oxygen.

1. What may happen after a supernova?
   A. It becomes a white dwarf
   B. It forms a neutron star or black hole
   C. It expands into a red giant
   D. The explosion is complete and nothing is left as a remnant

2. What is the estimated age of the universe according to modern cosmology?
   A. 4.6 billion years
   B. 13.7 billion years
   C. 38.3 billion years
   D. 51 billion years

3. Which of the following can be a consequence of strong solar storms on Earth?
   A. Increased global temperatures
   B. Disruptions in satellite communications
   C. Tsunamis in coastal regions
   D. Decreased aurora activity

4. What determines how long a star remains on the main sequence?
   A. Its rotation speed
   B. Its mass
   C. Its location in the galaxy
   D. Its number of planets

5. What is the event horizon of a black hole?
   A. The outermost layer of the black hole
   B. The distance where gravitational pull prevents light from escaping
   C. The point where a black hole stops growing
   D. The explosion that forms the black hole

6. What protects Earth from the harmful effects of most solar storms?
   A. The ozone layer
   B. The Moon's gravitational pull
   C. The magnetosphere
   D. The Earth's atmosphere alone

7. Which of the following stars is the brightest in the night sky?
   A. Polaris
   B. Betelgeuse
   C. Vega
   D. Sirius

8. Which of the following solar phenomena is responsible for causing geomagnetic storms on Earth?
   A. Sunspots
   B. Coronal Loop
   C. Filament
   D. Coronal Mass Ejections

9. Star A and Star B have the same absolute magnitude, but Star A is 3 times as far away from Earth as Star B. Select each true statement.
   A. Star A and Star B will have the same apparent magnitude.
   B. Star B will appear 9 times as bright from Earth as Star A.
   C. Star B will appear to be 3 times as bright as Star A when both are viewed from a distance of 10 parsecs.
   D. The apparent magnitude of Star A will be a greater number than the apparent magnitude of Star B.

10. How much brighter is a star with an apparent magnitude of 2 than a star with an apparent magnitude of 4?
    A. ≈ 2 times as bright
    B. ≈ 4 times as bright
    C. ≈ 6 times as bright
    D. ≈ 8 times as bright

11. Which property is most important in determining a star's classification on the Hertzsprung-Russell diagram?
    A. Distance from Earth
    B. Age of the star
    C. Temperature
    D. Number of planets orbiting it

12. Which of these structures is the largest?
    A. Galaxy
    B. Nebula
    C. Supercluster
    D. Star Cluster

13. Which of the following statements is true about main sequence stars?
    A. They fuse hydrogen into carbon.
    B. Their energy comes from nuclear fusion of hydrogen into helium.
    C. They do not emit significant radiation.
    D. They last for a few thousand years before burning out.

14. Which of these celestial objects do people observe as a faint smudge in the sky when stargazing?
   A. Galaxies outside of the Milky Way
   B. Red giant stars
   C. Black holes
   D. White dwarf stars

15. What will happen to the Sun when it runs out of hydrogen fuel in its core?
   A. It will explode as a supernova.
   B. It will collapse into a black hole.
   C. It will expand into a red giant.
   D. It will remain unchanged.

16. Which of these stars has the shortest lifespan as a star?
   A. A red dwarf
   B. A blue supergiant
   C. A yellow main sequence star
   D. An brown dwarf

17. What happens to a star where the pressure from fusion is greater than that of gravity?
   A. The star expands
   B. The star shrinks
   C. The star remains the same size

18. Which of the following stars is an example of a red supergiant?
   A. Sirius
   B. Betelgeuse
   C. Proxima Centauri
   D. Vega

19. Which of the following best describes the relationship between a star's mass and its lifespan?
   A. More massive stars live longer than smaller stars.
   B. More massive stars have shorter lifespans than smaller stars.
   C. A star's lifespan is unrelated to its mass.
   D. Larger stars live indefinitely because they generate more energy.

20. Which of the following constellations contains the star Polaris?
   A. Orion
   B. Ursa Minor
   C. Draco
   D. Cassiopeia

21. Why do astronomers sometimes use colored flashlights while stargazing?
   A. Red light is easier to see than white light.
   B. Red light does not affect night vision as much as white light.
   C. Red light doesn't interfere with the lenses in telescopes.

22. What is the most abundant element in the universe?
   A. Oxygen
   B. Carbon
   C. Hydrogen
   D. Iron

23. What two qualities of stars are plotted on an H–R Diagram?
   A. Mass
   B. Luminosity
   C. Diameter
   D. Temperature

24. During which of these phases will the sky be the darkest?
   A. Astronomical twilight
   B. Civil twilight
   C. Nautical twilight

Short Answer:

In terms of navigating the night sky, what is the difference between azimuth and altitude?

ALTITUDE IS THE ANGLE ABOVE THE HORIZON.

AZIMUTH IS THE ANGLE CLOCKWISE FROM DUE NORTH.

Explain the difference between an asterism and a constellation:

AN ASTERISM IS A RECOGNIZABLE PATTERN THAT CONNECTS PROMINENT STARS (FOR EXAMPLE, THE BIG DIPPER). A CONSTELLATION IS A REGION OF THE NIGHT SKY AND CONTAINS ALL THE STARS WITHIN THAT REGION (EX URSA MAJOR)

What type of star is our Sun?

THE SUN IS A G-TYPE MAIN SEQUENCE STAR, ALSO CALLED A "YELLOW DWARF."

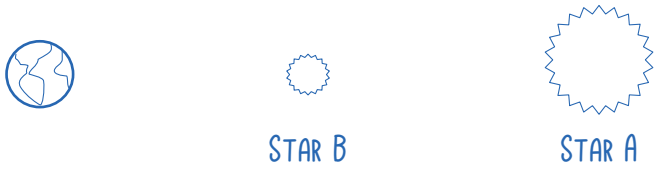
Explain how each scenario could happen or why it would be impossible. If desired, draw pictures of how the stars could be positioned relative to Earth:

- Star A has a greater *absolute magnitude* than Star B, but Star B has a greater ***apparent magnitude*** than star A.

  Star A produces more light than Star B, but star B appears brighter to people on Earth because it's so much closer to Earth than star A.

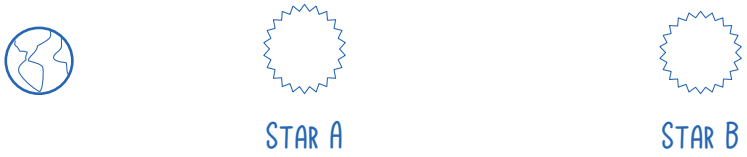
- Star A has a greater *absolute magnitude* than Star B, but Star A and B have the same ***apparent magnitude.***

  Star A produces more light than Star B, but the effect of their distances make them appear to have the same brightness to observers on Earth.



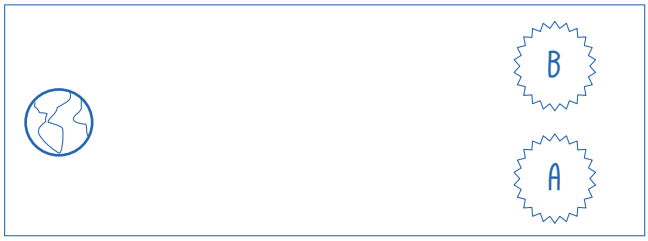
- Star A has a greater ***apparent magnitude*** than Star B, but Star A and B have the same *absolute magnitude.*

  Star A and Star B produce the same amount of light, but star A looks brighter from Earth because it's closer.



- Star A and Star B have the same *absolute magnitudes* and the same **apparent magnitudes**.

  Star A and Star B produce the same amount of light, and they look the same when viewed from Earth because they're the same distance away from Earth.



List the following systems in order from smallest to largest (galaxy, known universe, planetary system, star cluster)

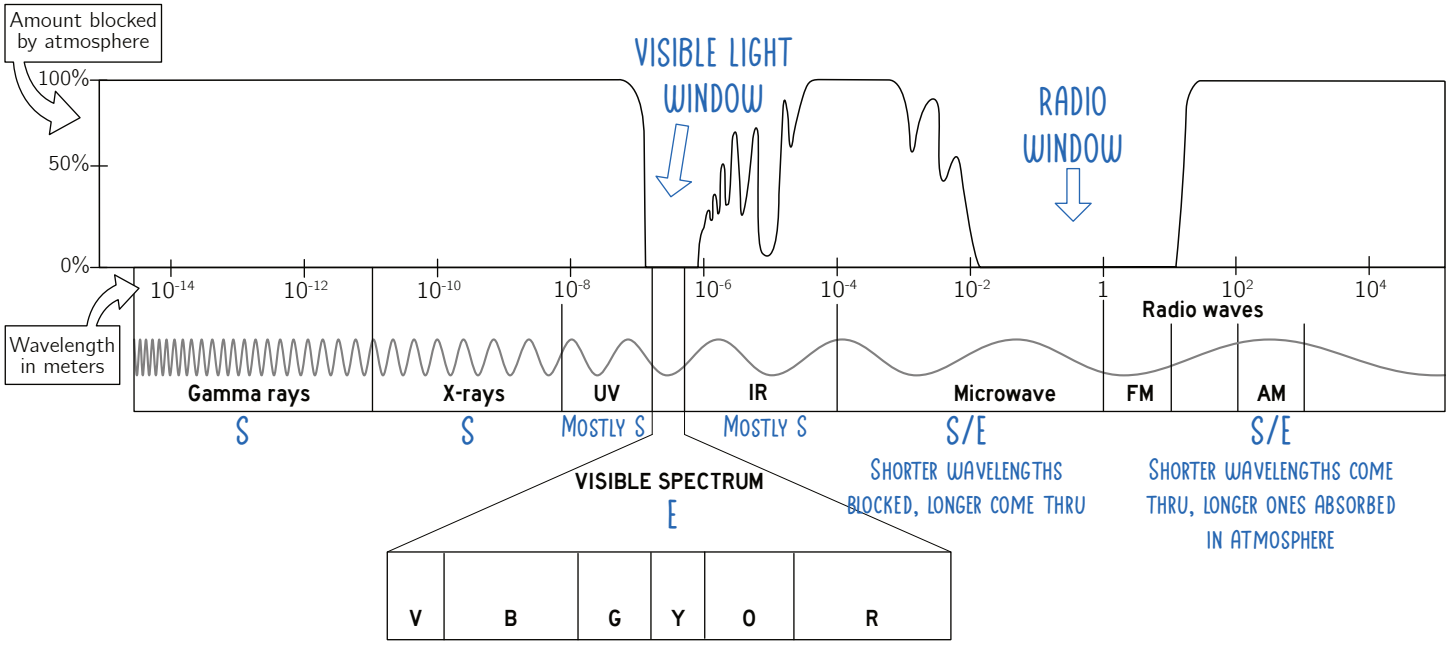
Planetary system < Star Cluster < Galaxy < Known Universe

Unit 4: Space Exploration

Telescopes

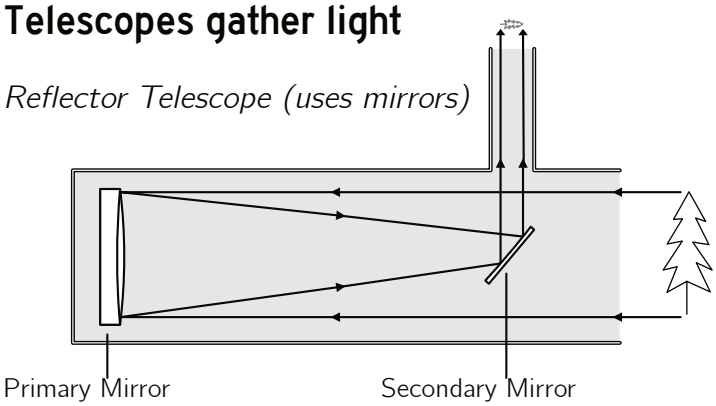
Visible light is only a small part of a larger spectrum of radiation! Our eyes see wavelengths from about 400-700 nanometers— that's thinner than a soap bubble film. But stars produce energy in waves that stretch from smaller than an atomic nucleus to longer than the tallest skyscrapers! Not all of that radiation makes it to Earth's surface.

Consider the graphic showing which wavelengths are blocked by Earth's atmosphere. Then write "E" below wavelengths that can be seen from Earth and "S" below those that can only be observed from space.

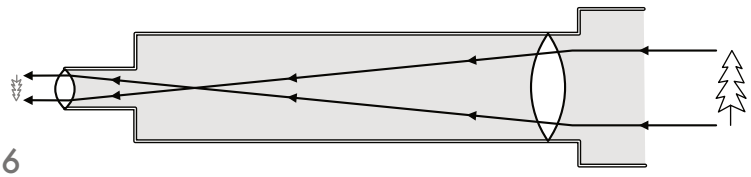


Telescopes gather light

Reflector Telescope (uses mirrors)



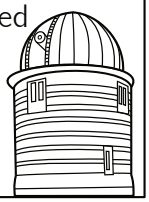
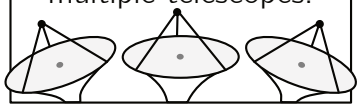
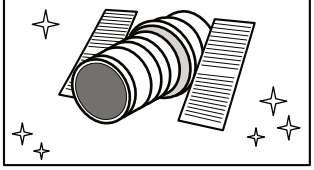
Refracting Telescopes (use lenses)



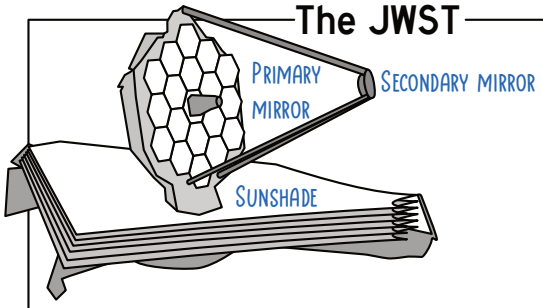
MANY TELESCOPES WORK BY GATHERING LIGHT FROM A DISTANT OBJECT AND FOCUSING IT THROUGH A LENS IN THE EYE PIECE.

TELESCOPES WERE FIRST INVENTED IN THE 1600S. EARLY MODELS USED LENSES AND MIRRORS, AND TELESCOPES THAT GATHER VISUAL LIGHT STILL USE THESE TODAY.

Match each telescope with the best description

Radio Telescope	Uses mirrors to gather and focus light. Commonly used in research observatories. 
Reflector Telescope	Looks like a giant dish antenna. Works during both day and night. Needs a network of multiple telescopes. 
Infrared Telescope	Operates outside of Earth's atmosphere. 
Space Telescope	Can see through cosmic dust clouds. Must be placed either high in Earth's atmosphere or in outer space.

The JWST



James Webb Space Telescope (JWST)

- Uses infrared light
- Located 1.5 million km away from Earth near Lagrange point 2
- Continually sends incredible images that change the way we understand our galaxy and universe!

How do telescopes see back in time?

Light has speed – the further away it comes from to reach a scope, the older it is. Looking at a star 500 light years away = looking at how the star appeared 500 years ago.

Is there a limit to how far we can see with a telescope?

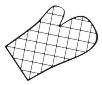
Yes, The age of the universe, which is estimated to be 13.7 billion years old. This means we can't see things further than about 13 billion light years. The furthest away star we've seen (with Hubble) was 12 billion light years away.

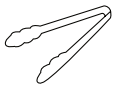
https://science.nasa.gov/missions/hubble/record-broken-hubble-spots-farthest-star-ever-seen/

Candy Bar Heat Shield

MATERIALS


6 paper cups

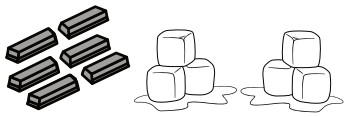

oven mitt


tongs


A variety of shielding materials such as newspaper, paper, cardboard, aluminum foil, electrical tape, egg cartons, bubble wrap, etc


Timer


Blow dryer


3 unwrapped chocolate candy bars, each cut in half
OR 6 ice cubes

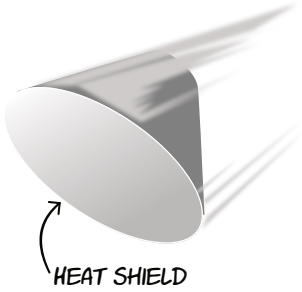
GOALS

- Design and create a heat shield.
- Refine and improve your design.
- Learn about heat transfer and insulation

One of the biggest challenges faced by spacecraft is re-entering the atmosphere without burning up.

To protect the astronauts and equipment, engineers design special heat shields like the one illustrated here that can withstand extreme temperatures.

In this activity you'll create your own heat shield—but instead of protecting a spacecraft, your job is to protect candy or ice.



When spacecraft return to Earth, they can be traveling more than 40,000 km/h– that's over 11 kilometers per second!

The extreme speed creates a plasma sheath that reaches temps well over 1,000°C.

Without a heat shield, astronauts would literally be cooked!

Instructions:

1. Set aside 1 cup. This will be your control. It will hold one piece of candy (or ice cube) and have no heat shield.

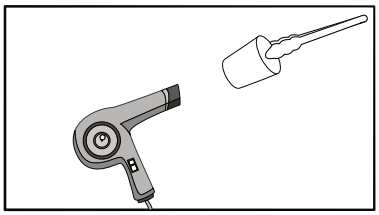
2. Design 2 heat shields that can cover the base of a paper cup. Use a different kind of material for each. Describe your design in the boxes here. Which do you predict will work better?

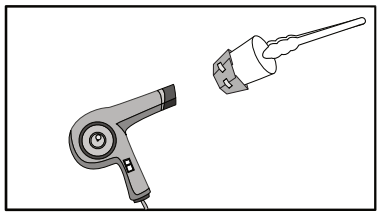
3. Build your heat shields. Each shield should be securely attached to a paper cup.

4. Set up the hair dryer and prepare the oven mitts and tongs. You'll want to hold each cup the same distance from the hair dryer.

CAUTION: Hair dryers can get very hot! If your heat shield or cup starts to melt, smell badly, or smoke, turn off the hair dryer immediately!

5. Set up the hair dryer so it's 10 cm (about 4 in) in front of the cup. You may need two or more people to get this set up. We recommend holding the cup with either tongs or an oven mitt.


Setup for testing control


Setup for testing heat shield

Idea for Heat Shield 1:

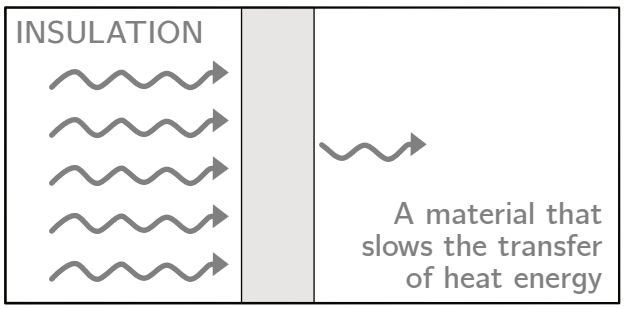
Idea for Heat Shield 2:

My most effective heat shield is predicted to be:

6. Turn on the dryer for 1 minute. Be sure to have a timer so you can apply the same amount of heat with each test.

7. Check the cup and see if there is any sign of melting. If you do observe melting, record that in your log.

8. Repeat steps 6 and 7. Repeat the heat treatment from the blow dryer 5 times. If no melting is observed after 5 minutes of heat exposure, congratulations you have created a successful heat shield!



	Time until first melting observed (in minutes)	Time until completely melted (if applicable)
CONTROL *(the cup alone with no shield)*		
Design 1		
Design 2		

9. Evaluate your designs. Which heat shield design was most effective? Do you have any ideas for how to improve the design?

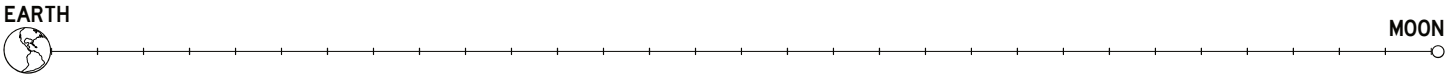
10. Refine or redesign new heat shields and test them. Repeat steps 6 and 7 to test each cup. Were you able to improve your design?

	Time until first melting observed (in minutes)	Time until completely melted (if applicable)
CONTROL *(the cup alone with no shield)*		
Revised Design 1		
Revised Design 2		

Notes:

The Moon Missions

How did people overcome these challenges in reaching our nearest neighbor?



CHALLENGE 1:
Generate enough thrust to escape Earth's orbit.

NASA developed a 3-stage rocket called the Saturn V. Heavier stages could be dropped when empty.

It was 363 feet or 111 meters tall and remains the most powerful rocket ever successfully launched.

CHALLENGE 2:
Make a spacecraft capable of landing and returning.

Create a modular spacecraft.

- The lunar module would be light to land on the moon.
- The command module would survive reentry.

CHALLENGE 3:
Navigate the vast distance (over 384,000 km)

NASA developed complex mathematical models for trajectory planning.

- The Apollo Guidance Computer allowed for mid-course adjustments.
- Astronauts manually confirmed navigation using a sextant to sight stars.

Human Health Hazards

What makes each of these things hazardous to the human body, and what can be done to prevent that hazard or protect people from the danger?

Weightlessness

The danger:

Severe muscle and bone loss

Prevent or protect:

Exercise at least 2 hours every day.

Radiation

The danger:

Damage to DNA, increased cancer risk, radiation sickness and death

Prevent or protect:

Radiation shielding on spacecraft and spacesuits. Mission timed to avoid solar storms.

Vacuum of Space

The danger:

Near-instant death when air inside lungs leaves and saliva in mouth evaporates or boils away

Prevent or protect:

Multiple layers of shielding in spacesuits and ships, astronauts trained in rapid response drills for loss of pressure in cabin.

Moon Dust

The danger:

Toxic superfine particles cause "lunar hayfever" and damage equipment

Prevent or protect:

Try to improve seals, perhaps special coatings or electric fields to repel/remove dust.

Fill in the following milestones of Lunar exploration:

1950 1960 1970 1980 1990 2000 2010 2020 2030

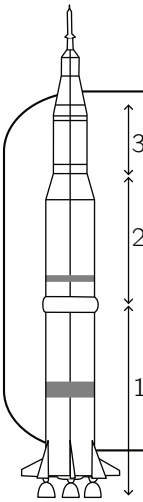
1959 Luna 2: First spacecraft to impact the Moon

1968 Apollo 8: First people to orbit the Moon

1969 Apollo 11: First people to walk on the Moon

2013 Chang'e 3: After 40 years of no rovers, the Yutu rover lands on the Moon.

2019 Chang'e 4: First rover to explore the far side of the Moon.



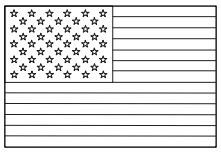
Why does a rocket have stages?

Because the amount of fuel needed to escape Earth's gravity is so enormous, that a device large enough to carry all that fuel is effectively too heavy to be functional.

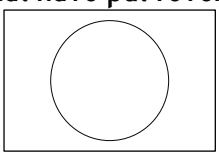
With staging, after the fuel is burned the structural "dead weight" of the empty tank is dropped. This allows the rest of the rocket move more efficiently because it has less mass.

Discarding discrete amounts of now-useless structural mass is called "staging."

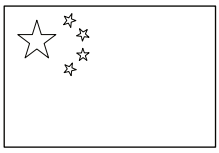
Name the 5 countries that have put rovers on the Moon:



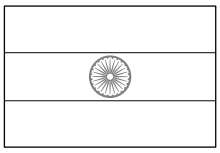
USA: Apollo lunar rovers 1971 & 1972



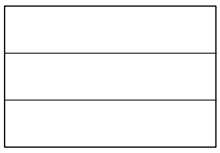
Japan: LEV rovers 2024



China: Yutu and Cheng'e rovers 2013-present(2025)



India: Pragyan rover 2023

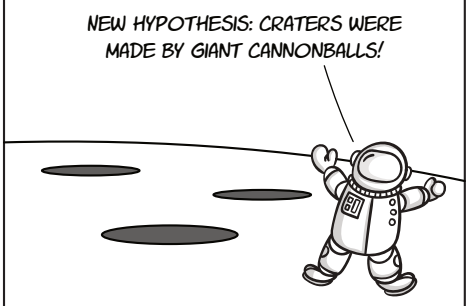


Russia: Lunokhod rovers 1970-1973

Fact or Fiction?

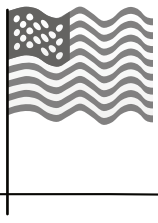
Consider each statement, then write whether it is fact or fiction.

The Moon smells like gunpowder.



Fact: Apollo astronauts reported that lunar dust had a scent like burnt gunpowder.

The U.S. flag planted on the Moon still flutters in the wind.



Fiction: There can be no wind because there's no atmosphere. The flag had a rod across the top for support.

The Apollo 11 crew was isolated for 3 weeks after returning to Earth.

Fact: NASA feared Moon microbes could pose a risk so they kept the astronauts quarantined for 21 days.

Living in Space

Why explore?

Why would people consider establishing bases on other planets or moons in the solar system?

For the challenge and adventure of exploring new areas.

Because Earth will eventually become uninhabitable (over 1 billion years from now) due to the Sun expanding into a red giant.

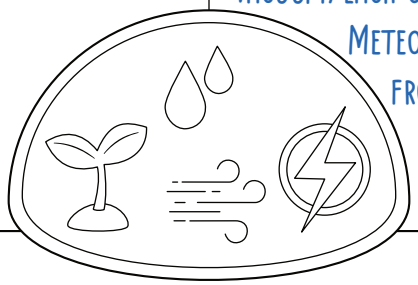
Functions of a Space Base

A space base/station must provide an environment where humans can survive. List what is needed:

Warmth, Power, water, food, air, waste management

A space station must protect people from the dangers of outer space. List some of the dangers:

Vacuum/lack of atmosphere, Extreme cold, Meteorites, Toxic dust, Radiation, Bone loss from microgravity, psychological challenges (confinement, isolation)



Beyond Earth: Where could people live?

	Distance from Earth in km	Time to travel there	Resources (atmosphere, water, minerals, sunlight for solar power)	Feasibility Rating What's your opinion?
Space Station	408 km	3 days	No water/minerals. Lots of sunlight	☆☆☆☆☆
The Moon	384,400 km	3 days	Water (at south pole). Minerals (Silica & iron.) Lots of sunlight.	☆☆☆☆☆
Mars	$2.25 \cdot 10^8$ km	7-9 months	Water as subsurface permafrost. CO_2 in atmosphere. Good amount Sunlight.	☆☆☆☆☆
Asteroid Belt (Ceres)	$2.57 \cdot 10^8$ km	1+ years	Abundant water (frozen). Minerals. Sunlight is weaker/less bright.	☆☆☆☆☆
Europa	$7.78 \cdot 10^8$ km	3+ years	Abundant water (frozen on surface, liquid ocean below) Weak sunlight.	☆☆☆☆☆
Titan	$1.4 \cdot 10^9$ km	6+ years	Water (frozen). Thick nitrogen atmosphere. Weak sunlight, solar not a viable power option.	☆☆☆☆☆

Which of these locations is best for a space station and why?

Answers will vary. They might include arguments in favor of deeper space exploration, the importance of first taking care of Earth and our resources here, the practicality of a Moon base due to distance and resupply costs, or other ideas.

Considerable Hazards

Consider the hazards caused by micrometeorites, radiation exposure, and microgravity. Of those three, which represents the greatest challenge to permanent human settlements outside of Earth and why? Can you think of a solution to this issue?

Answers will vary. Micrometeorites could break structures. Compartments and shielding could help prevent severe damage from depressurization. Radiation causes increased cancer risk and DNA damage. Underwater habitats (such as on Europa) would provide protection. Microgravity causes bone loss. Exercise helps prevent severe loss (and if not returning to Earth, bone loss may not matter as much)

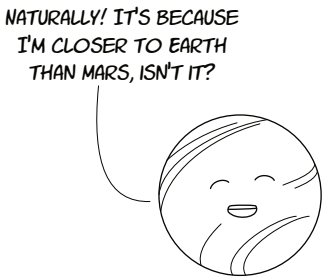
Journal

Choose a location for a settlement in outer space. Draw what the view would look like from a window there. Then write a journal entry describing a typical day on the base.

Fact or Fiction?

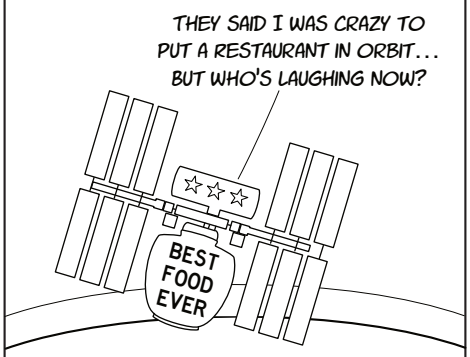
Consider each statement, then write whether it is fact or fiction.

NASA plans to colonize the surface of Venus by 2050.



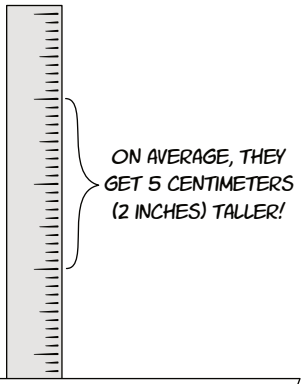
Fiction! The environment is too hostile. However, we have considered floating bases in the upper-middle atmosphere of Venus.

Food tastes better in a weightlessness environment than on Earth.



Fiction! Microgravity causes bodily fluid shifts that can dull the sense of taste. Spicy or tangy foods become popular choices for many orbiting astronauts.

Astronauts on the ISS grow taller while in orbit.



Fact! In microgravity, the spine decompresses slightly, making astronauts temporarily taller—though they shrink back soon after returning to Earth's gravity.

FINAL REVIEW

1 If a location has more daylight on December 21 than June 21, then which hemisphere is in?

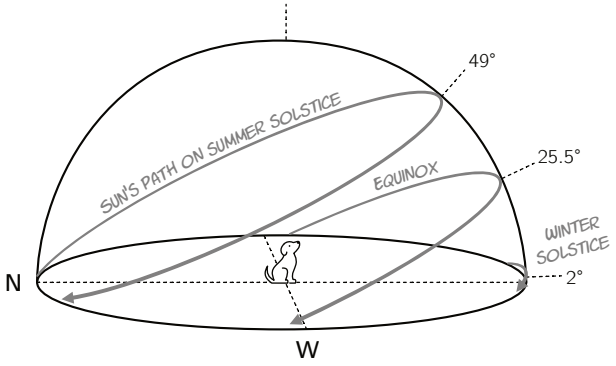
A. Northern hemisphere
B. Southern hemisphere
C. There is not enough information to tell

2 City W in the Northern Hemisphere is 35 degrees further south than city Z. Which of the following statements are true?

A. On June 21, city W will have fewer hours of daylight than city Z.
B. On June 21, city W will have more hours of daylight than city Z.
C. In June, both cities are experiencing their longest days of the year (summer)
D. In June, both cities are experiencing their shortest days of the year (winter)

3 The illustration below shows the Sun's apparent path across the sky during each solstice and equinox. Which location matches the illustration?

A. Svalbard, Norway
B. Fairbanks, Alaska
C. Havana, Cuba
D. Singapore
E. Rio de Janeiro, Brazil
F. Bluff, New Zealand



4 How did you know which city this sun path illustration belonged to?

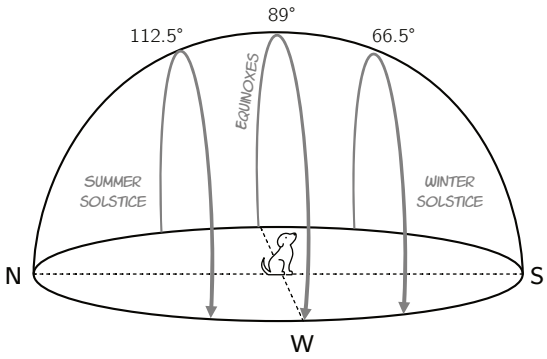
FAIRBANKS, ALASKA. THIS LOCATION IS FAIRBANKS, ALASKA BECAUSE IT HAS VERY LONG DAYS AT SUMMER SOLSTICE AND VERY SHORT DAYS DURING WINTER SOLSTICE WITH JUST A FEW HOURS OF DAYLIGHT. ALSO, THE ANGLE OF THE SUN AT ITS HIGHEST POINT ABOVE THE HORIZON AT EQUINOX WILL BE EQUAL TO 90°-THE LOCATION'S LATITUDE. 25.5° = 90°-64.5°.

5 City Q in the Southern Hemisphere is 40 degrees south of city P. Which of the following statements are true?

A. On June 21, city Q will have fewer hours of daylight than city P.
B. On June 21, city Q will have more hours of daylight than city P.
C. In June, both cities are experiencing their longest days of the year (summer)
D. In June, both cities are experiencing their shortest days of the year (winter)

6 Berlin, Germany experiences more hours of daylight on June 1st than Montreal, Canada. Therefore:

A. Berlin is further North than Montreal
B. Montreal is further North than Berlin
C. Berlin and Montreal are on the same line of latitude.



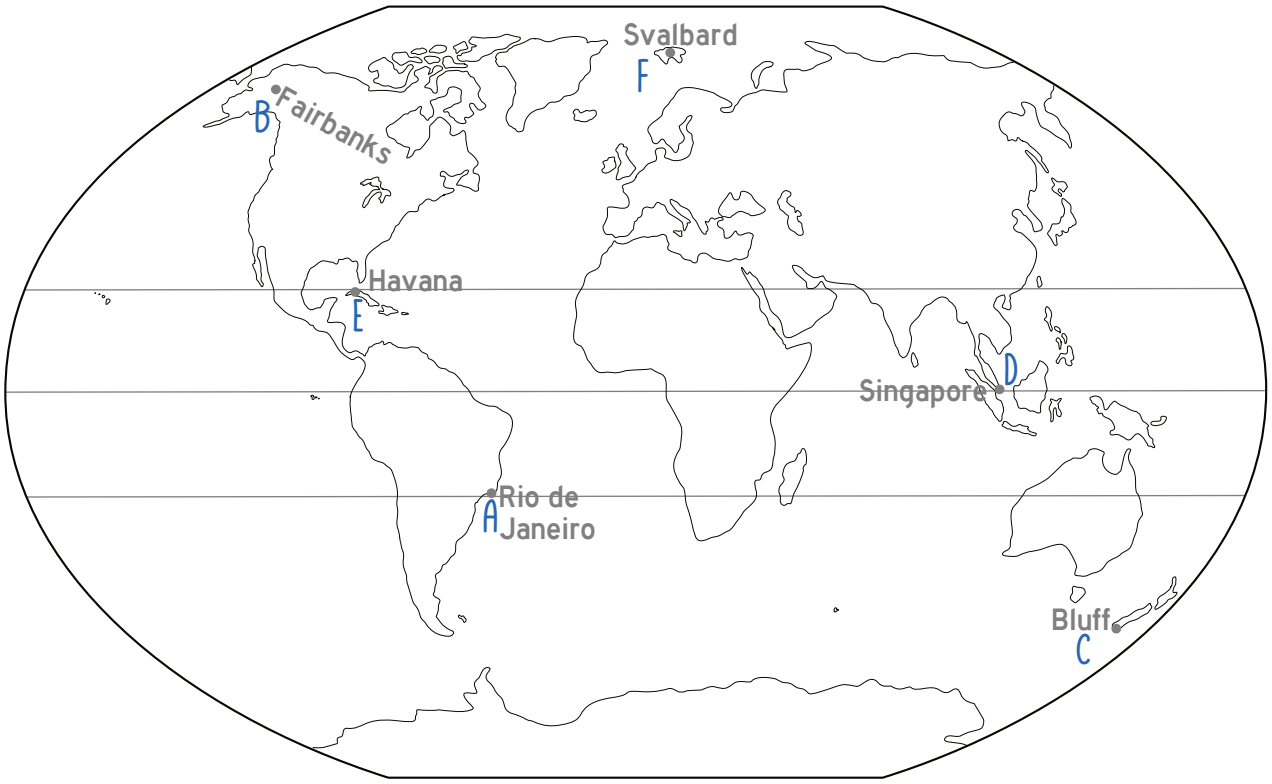
7 The above illustration shows the Sun's apparent path across the sky during each solstice and equinox. Which location matches the illustration?

A. Svalbard, Norway
B. Fairbanks, Alaska
C. Havana, Cuba
D. Singapore
E. Rio de Janeiro, Brazil
F. Bluff, New Zealand

How did you know which city this sun path illustration belonged to?

SINGAPORE. THIS LOCATION IS SINGAPORE BECAUSE THE SUN IS ALMOST DIRECTLY OVERHEAD FOR BOTH EQUINOXES AND THERE IS A SIMILAR AMOUNT OF DAYLIGHT YEAR ROUND. ALSO, THE ANGLE OF THE SUN AT ITS HIGHEST POINT ABOVE THE HORIZON AT EQUINOX IS EQUAL TO 90°-THE LOCATION'S LATITUDE. 89° = 90°-1°.

8 Calculate the approximate hours of daylight for each solstice and equinox listed below. Then use the daylight data to label each city on the map.



City A

Rio de Janeiro, Brazil
22°57′ S 43°12′ W

	Sunrise	Sunset	Approximate hrs of daylight
Jun 21	6:33 am	5:16 pm	10 h 43 min
Sep 21	5:42 am	5:48 pm	12 hr 6 min
Dec 21	5:04 am	6:37 pm	13 hr 33 min
Mar 21	5:56 am	6:01 pm	12 hr 5 min

City B

Fairbanks, USA
64°50′ N 147°43′ W

	Sunrise	Sunset	Approximate hrs of daylight
Jun 21	2:57 am	12:47 am	21 h 50 min
Sep 21	7:32 am	7:52 pm	12 hr 20 min
Dec 21	10:58 am	2:40 pm	3 hr 42 min
Mar 21	7:45 am	8:11 pm	12 hr 26 min

City C

Bluff, New Zealand
46°36′ S 168°20′ E

	Sunrise	Sunset	Approximate hrs of daylight
Jun 21	8:31 am	5:05 pm	8 h 34 min
Sep 21	6:37 am	6:42 pm	12 hr 5 min
Dec 21	5:49 am	9:39 pm	15 hr 50 min
Mar 21	7:49 am	7:57 pm	12 hr 8 min

City D

Singapore, Singapore
1°17′ N 103°51′ E

	Sunrise	Sunset	Approximate hrs of daylight
Jun 21	7:00 am	7:12 pm	12 h 12 min
Sep 21	6:54 am	7:00 pm	12 hr 6 min
Dec 21	7:01 am	7:04 pm	12 hr 3 min
Mar 21	7:08 am	7:15 pm	12 hr 7 min

City E

Havana, Cuba
23°08′ N 82°21′ W

	Sunrise	Sunset	Approximate hrs of daylight
Jun 21	6:44 am	8:18 pm	13 h 34 min
Sep 21	7:18 am	7:26 pm	12 hr 8 min
Dec 21	7:06 am	5:49 pm	10 hr 43 min
Mar 21	7:32 am	7:41 pm	12 hr 9 min

City F

Svalbard, Norway
78°13′N 15°39′E

	Sunrise	Sunset	Approximate hrs of daylight
Jun 21	*up all day*	*up all day*	24 hr
Sep 21	6:24 am	7:12 pm	12 hr 48 min
Dec 21	*down all day*	*down all day*	0 hr
Mar 21	5:40 am	6:32 pm	12 hr 52 min

Sunrise and sunset times are from timeanddate.com

9. Which of the following statements is true?
   A. Earth rotates along the plane of the ecliptic
   B. Earth rotates along the equatorial plane
   C. Earth revolves along the plane of the ecliptic
   D. Earth revolves along the equatorial plane

10. Which phenomenon best explains why we see different constellations in the sky at different times of the year?
   A. Rotation of the Earth around its axis
   B. Precession or wobble of Earth's axis
   C. Revolution of the Earth around the Sun
   D. Gravitational bending of starlight by the Sun

11. Select each phenomenon that is caused by the Earth's axial tilt.
   A. Day length changing throughout the year
   B. Ocean tides
   C. A 24-hour day
   D. Seasons
   E. The phases of the moon
   F. Equatorial bulge (Earth being an spheroid that is wider at the equator than poles)

12. The term "Main Sequence" refers to:
   A. The period in a star's life when it fuses hydrogen into helium in its core
   B. The phase where a star forms planetary systems
   C. The point at which a star becomes a white dwarf
   D. The time of fastest rotation for a star

13. Dark matter is:
   A. Another term for black holes
   B. Matter that emits enormous amounts of light
   C. The same as antimatter
   D. A form of matter that does not interact with electromagnetic radiation

14. What was the first clear evidence of an expanding universe?
   A. The light of distant galaxies being "redshifted"
   B. Increased brightness of distant stars
   C. Variations in Earth's gravitational field
   D. The discovery of black hole collisions

15. Select each true statement.
   A. One parsec is about 3.26 light-years
   B. Proxima Centauri is about 10 parsecs from Earth
   C. Any two objects that are one parsec away from Earth will have the same apparent magnitude
   D. A parsec is a measure of time

16. The color of a star is primarily determined by:
   A. Distance from Earth
   B. Temperature
   C. Diameter
   D. Age

17. What is the primary distinction between a meteoroid, meteor, and meteorite?
   A. Their temperature
   B. Whether they are composed of rock or ice
   C. Their location relative to Earth's atmosphere
   D. Whether they orbit the Sun or a planet

18. In stellar evolution, a massive star (much larger than the Sun) will typically end its life as a:
   A. White dwarf
   B. Red dwarf
   C. Neutron star or black hole
   D. Brown dwarf

19. Earth's closest approach to the Sun is known as:
   A. Aphelion
   B. Perihelion
   C. Equinox
   D. Solstice

20. The lunar highlands on the Moon are believed to be:
   A. Younger than the lunar maria
   B. Older than the lunar maria
   C. Artificial structures created by space debris
   D. Filled with subglacial lakes

21. The Hertzsprung–Russell (H-R) Diagram primarily plots a star's:
   A. Distance versus luminosity
   B. Brightness versus age
   C. Luminosity versus surface temperature
   D. Mass versus composition

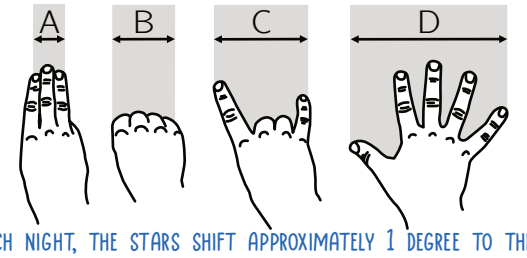
22. Which of the following is true about blue giant stars?
   A. They only fuse hydrogen into helium
   B. They are some of the longest-lived stars in the universe
   C. They are some of the shortest-lived stars in the universe
   D. Their remnants always form black holes

23. Which element is the main fuel in the core of a star during its longest, most stable phase?
   A. Carbon
   B. Helium
   C. Hydrogen
   D. Iron

24. Which event marks the transition of a protostar into a main-sequence star?
   A. The onset of carbon fusion
   B. The collapse of the protostar into a neutron star
   C. The beginning of fusion in the core
   D. The star ejects its outer layers

25. Which term describes the apparent motion of nearby stars against a more distant background, caused by Earth's orbit around the Sun?
   A. Parallax
   B. Aberration
   C. Precession
   D. Refraction

26. You go stargazing at midnight and notice the Big Dipper. When your hand is held at arm's length, where will the Big Dipper appear two weeks later at midnight, rotated relative to the North Star?
   A. Counterclockwise about 3 finger-lengths
   B. Clockwise about 1 palm-length
   C. Counterclockwise about the distance from index finger to pinky with fingers outstretched
   D. Clockwise about the distance from the spread out thumb to pinky finger



Each night, the stars shift approximately 1 degree to the west, so after 2 weeks the stars will appear to be about 14° west. C is the best answer because A is 5°, B is 10°, C is 15°, and D is 25°.

27. When is the Sun directly overhead at noon for an observer in the continental United States?
   A. Only during a total solar eclipse
   B. During the summer solstice
   C. Never, because it only occurs between the Tropic of Cancer and the Tropic of Capricorn
   D. Twice per year at the equinoxes

28. Label Kepler's Laws below. Careful. One is an imposter.

2 A line segment joining a planet and the Sun sweeps out equal areas during equal intervals of time.

~~A planet's orbital speed is directly~~ proportional to its distance from the Sun.

1 The orbit of a planet is an ellipse with the Sun at one of the focus points.

3 The orbital period is the square root of the cube of the length of the semi-major axis of its orbit.

29. Which of the following statements about Mercury is correct?
   A. It has a dense atmosphere rich in nitrogen
   B. It takes longer to rotate on its axis than it does to orbit the Sun
   C. It has the largest volcano in the Solar System
   D. It has no metal core and is composed only of silicate rock

30. Select each dwarf planet below.
   A. Ganymede
   B. Ceres
   C. Eris
   D. Enceladus
   E. Deimos

31. When an observer on Earth sees Mars undergo "retrograde motion," it appears to:
   A. Move in a perfect circle around the Sun
   B. Travel east to west among the background stars, rather than its usual west to east
   C. Rapidly accelerate in its orbit and disappear behind the Sun
   D. Become invisible as it enters Earth's shadow

32. Which health hazards from space are negated by Earth's atmosphere and magnetic field?
   A. Damage from micrometeorites
   B. Bone loss from low gravity
   C. Increased cancer from radiation
   D. Death due to lack of air pressure

33. What was the first human-made object to reach the Moon?
   A. Sputnik
   B. Apollo 11
   C. Luna 2
   D. Yutu 2

34. What is these factors makes landing spacecraft on Mars extra challenging?
   A. The thin atmosphere
   B. Cold temperatures
   C. The long travel time
   D. The planet's magnetic field

35. What type of propulsion system to spacecraft use to escape Earth's gravity?
   A. Solar sails.
   B. Nuclear fusion engines
   C. Warp drive
   D. Chemical rockets

36. What space program was first to land a rover on Mars?
   A. European Space Agency (ESA)
   B. National Aeronautics and Space Administration (NASA)
   C. China National Space Administration (CNSA)
   D. Japan Aerospace Exploration Agency (JAXA)

37. What natural resource on the Moon could be used to produce rocket fuel?
   A. Helium
   B. Water Ice
   C. Silica
   D. Iron

38. Which of these are an advantage of an infrared space telescope?
   A. It can see the highest-frequency and most energetic wavelengths of light
   B. It can see through dust clouds
   C. It can see objects that are invisible to reflector telescopes

39. Why is Europa a potentially interesting moon for further research?
   A. It's the most volcanically active object in the solar system
   B. Its underwater oceans are likely to harbor life
   C. It has a thick atmosphere and rivers of liquid methane

Short Answer

40. Explain why it is much more difficult to land a spacecraft on Mars than on the Moon.

The Moon has no atmosphere and relatively weak gravity (0.165 G) so spacecraft land using thrusters. The same approach doesn't work on Mars because the gravity is stronger (0.38 G), making the fuel load for a thruster-only landing infeasible or impossible. Also, Mars has a thin atmosphere! It has just enough atmosphere to create problems (friction, heat, and turbulence) but not enough to be fully useful for slowing down spacecraft with parachutes. For larger spacecraft, it is not possible to land safely on Mars with current technology and systems.

41. List 3 telescopes that operate in space:

There are more than 20! Some of the most famous are Hubble, James Webb Space Telescope (JWST), Chandra X-ray telescope, and International Gamma Ray Astrophysics Laboratory (INTEGRAL).

42. What celestial object (besides Earth) has been visited by the most spacecraft?

The Moon (over 140 missions). Mars is number 2 with approximately 50 missions.

Mad Lib

Ask someone for a word that matches each part of speech to fill in the words below.

In 240 BCE (year), a scholar named ERATOSTHENES (proper noun) used a clever method to measure Earth's CIRCUMFERENCE (noun). He knew that at NOON (time) on the summer solstice, the Sun's RAYS (plural noun) shone directly down a WELL (noun) in the city of SYENE (location), creating no SHADOW (noun) at all. Meanwhile, in Alexandria, located 5,000 STADIA (distance) away, the SUN (noun) cast a shadow measuring about 7.2 (number) degrees. Using geometry, ERATOSTHENES (proper noun) multiplied this fraction of a circle by the 5,000 STADIA (unit of measure) to find the entire circumference of our PLANET (noun), achieving a remarkably accurate result!

Original text is filled in, but you can fill in the Mad Lib any way you'd like.

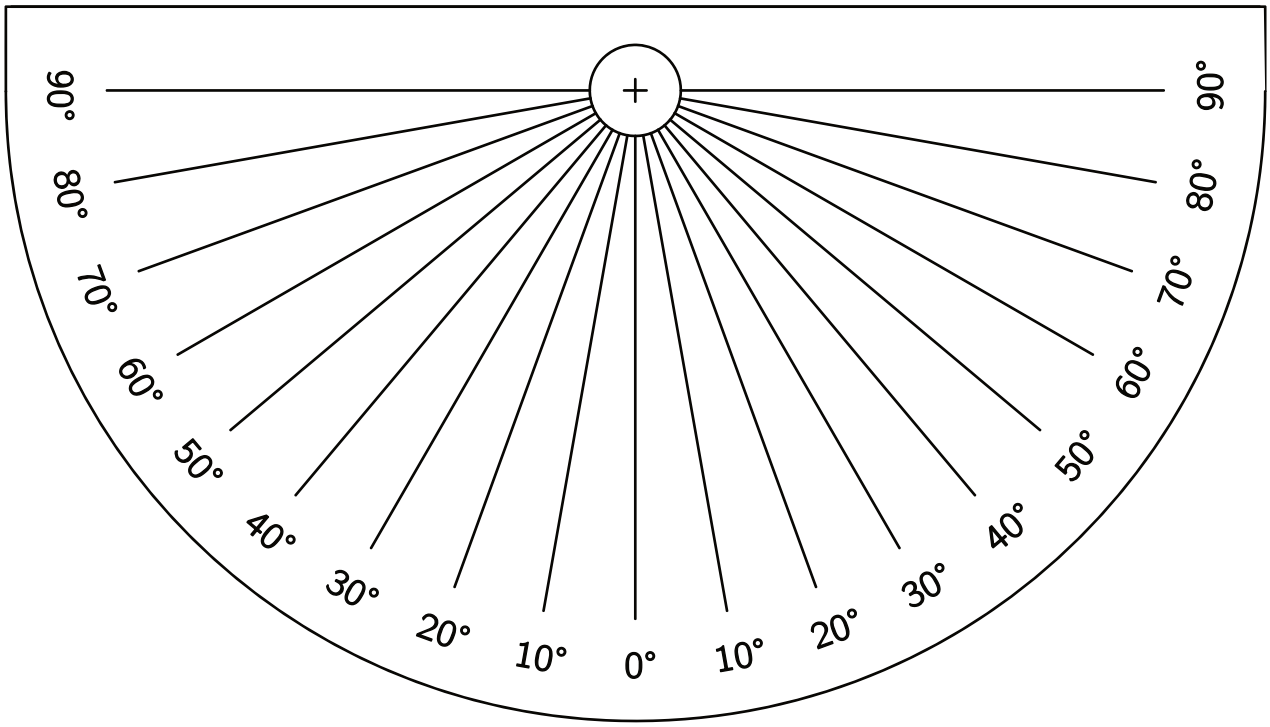
Anagrams

Unscramble each word or phrase below to make an astronomy term.

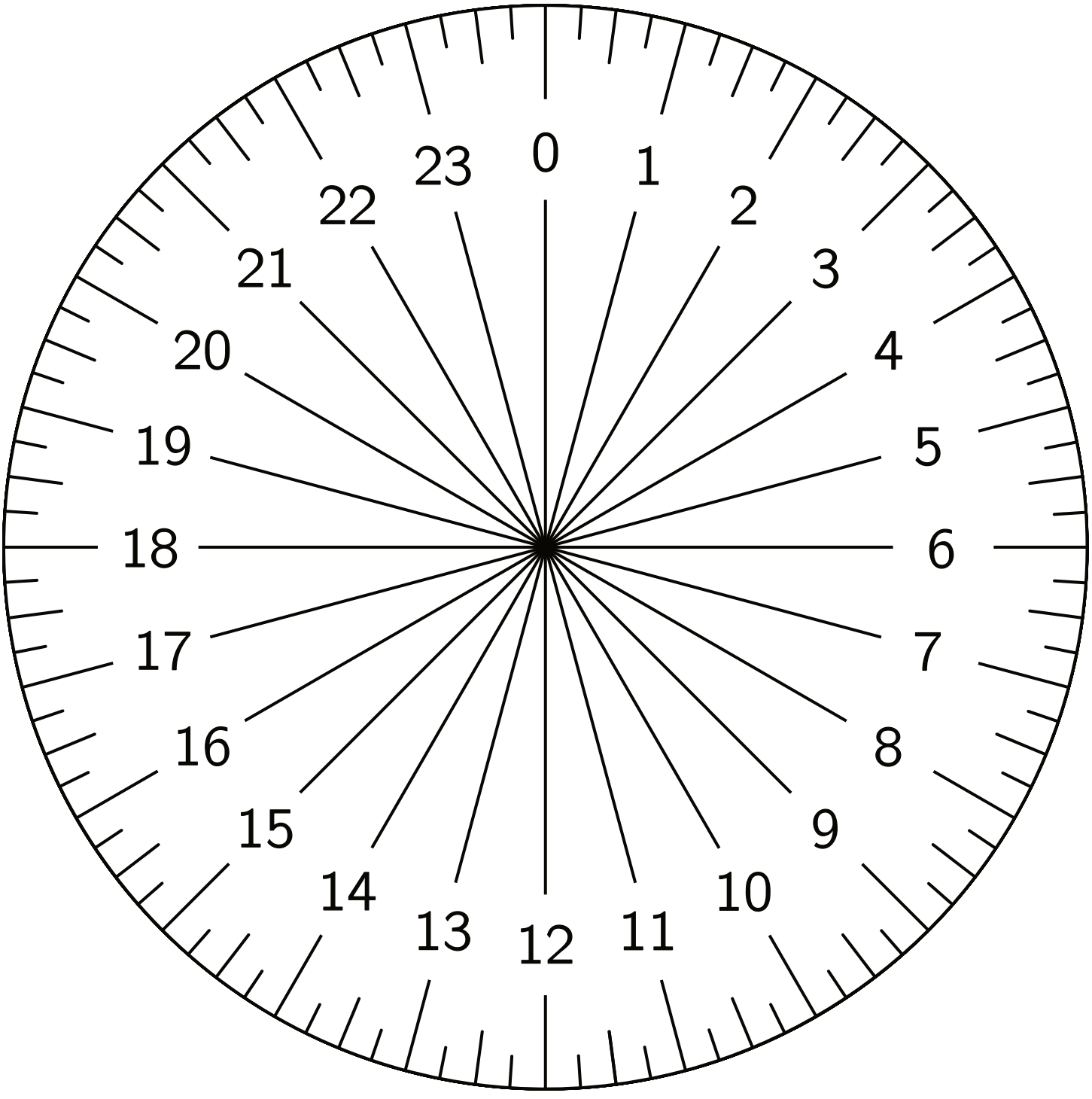
ANAGRAM	VOCAB WORD	2-WORD DESCRIPTION
EDIT OARS *REARRANGE LETTERS*	ASTEROID	Space rock
MOON STARER	ASTRONOMER	Sky scientist
MARKET DART	DARK MATTER	Invisible mass
DICTION CREAKS	ACCRETION DISK	Spinning gas
CEREAL SPOILS	SOLAR ECLIPSE	Moon shadow
RENTAL SPAM	PLANET MARS	Red world
USA PROVEN	SUPERNOVA	Stellar explosion
TITAN COLONELS	CONSTELLATION	Star pattern
MATH UZI	AZIMUTH	Horizontal angle
ELLIPSES TEACHER	CELESTIAL SPHERE	Sky dome
ABHORRENT EJECTA	NEAR EARTH OBJECT	Close traveler
CHALK LOBE	BLACK HOLE	Gravity trap
REMOTE TIE	METEORITE	Fallen fragment
HEROIC CLIENT	HELIOCENTRIC	Sun-centered
MUTINY SOIL	LUMINOSITY	Brightness measure
DOCTOR LOU	OORT CLOUD	Comet nursery
BOILED AIRPORT	ORBITAL PERIOD	Revolution time
NUMB PEAR	PENUMBRA	Partial shadow

APPENDIX

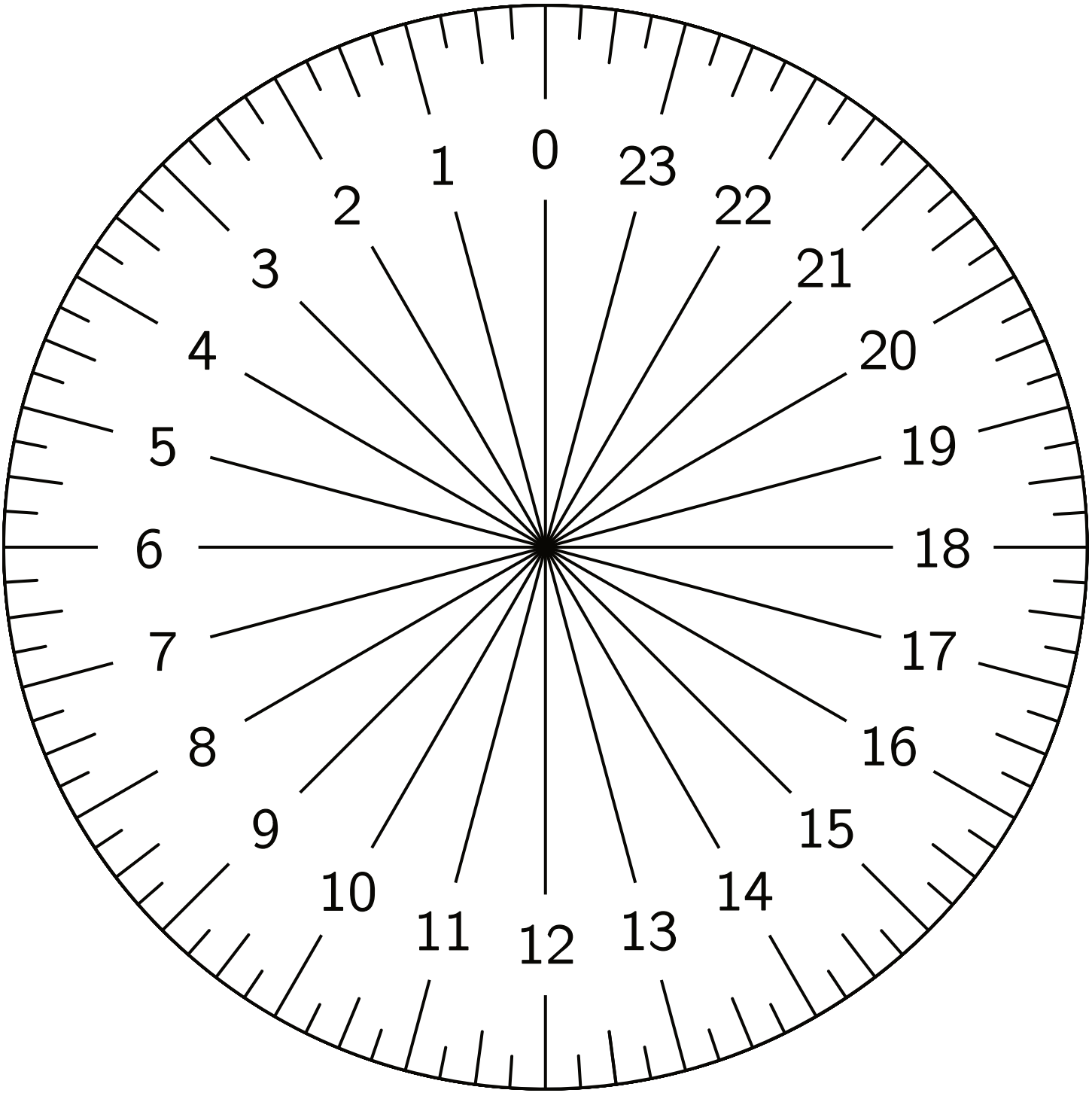
Protractor Template for **Measure Your Latitude** Activity



North Facing Sundial Template for **DIY Equatorial Sundial** Activity



South Facing Sundial Template for **DIY Equatorial Sundial** Activity



Planet Templates for the Step Scale Model of the Solar System

Cut these out and use them to create your step-scale model of the solar system! You can place them on the ground at the various locations indicated by the step-scale chart, or you can assign a person to stand at each location and hold that particular paper.

If we scale the solar system down by a factor of 10 billion, the Sun would have the diameter of 70 mm. That's as large as this circle (providing this page is printed on standard 8.5x11 paper).

The Sun (Sol)

But how far apart would the planets be? Cut out these papers and use the step scale to find out! Measure your steps and see if you can walk in a way that approximates 2 steps per meter. If stepping is too inconsistent, you could use a yardstick or tape measure instead.

1. Mercury

Using a scale factor of 1/10,000,000,000 the planet Mercury would be 0.24 mm in diameter (as big as the dot in this box). It would be 3 meters from the Sun.

6 Steps from the Sun

·
Mercury

2. Venus

Using a scale factor of one ten billionth, the planet Venus would be 0.61 mm in diameter (as big as the dot in this box) and be 6.5 meters from the Sun.

11 Steps from the Sun, 5 steps from Mercury

·
Venus

3. Earth

Using a scale factor of 1/10,000,000,000, the planet Earth would be 0.63 mm in diameter (as big as the dot in this box). It would be 7.5 meters from the Sun.

15 Steps from the Sun, 4 steps from Venus

·
Earth

4. Mars

Using a scale factor of one ten billionth, the planet Mars would be 0.34 mm in diameter (as big as the dot in this box) and be 11.5 meters from the Sun.

23 Steps from the Sun, 8 steps from Earth

·
Mars

5. Jupiter

Using a scale factor of 1/10,000,000,000, the planet Jupiter would be 7 mm in diameter (as big as the circle in this box). It would be 39 meters from the Sun.

78 Steps from the Sun, 55 steps from Mars

Jupiter

6. Saturn

Using a scale factor of one ten billionth, the planet Saturn would be 6 mm in diameter (as big as the figure in this box) and be 71.5 meters from the Sun.

143 Steps from the Sun, 65 steps from Jupiter

Saturn

7. Uranus

Using a scale factor of 1/10,000,000,000, the planet Uranus would be 2.6 mm in diameter (as big as the circle in this box) and be 143.5 meters from the Sun.

287 Steps from the Sun, 144 steps from Saturn

Uranus

8. Neptune

Using a scale factor of one ten billionth, the planet Neptune would be 2.5 mm in diameter (as big as the circle in this box) and be 224.5 meters from the Sun.

451 Steps from the Sun, 164 steps from Uranus

Neptune

9. Kuiper Belt

Using a scale factor of 1/10,000,000,000, the most famous object in the Kuiper Belt (Pluto) would be 0.12 mm in diameter and 295.5 meters from the Sun.

591 Steps from the Sun, 140 steps from Neptune

Pluto

10. Oort Cloud

Using a scale factor of one ten billionth, the Oort cloud would begin approximately 75 km from the Sun; that's 150,000 steps! The end of the Oort cloud may stretch to as much as 1,500 kilometers from the Sun. Can you identify a city or landmark that is approximately 75 kilometers from your model Sun?

75 kilometers or 46.6 miles

The closest star system

Using a scaling factor of 1/10,000,000,000, Alpha Centauri, the nearest star system to the Sun, would be 4,131 kilometers away! That's approximately the distance from LA to Boston, or from Beijing, China to Kabul, Afghanistan.

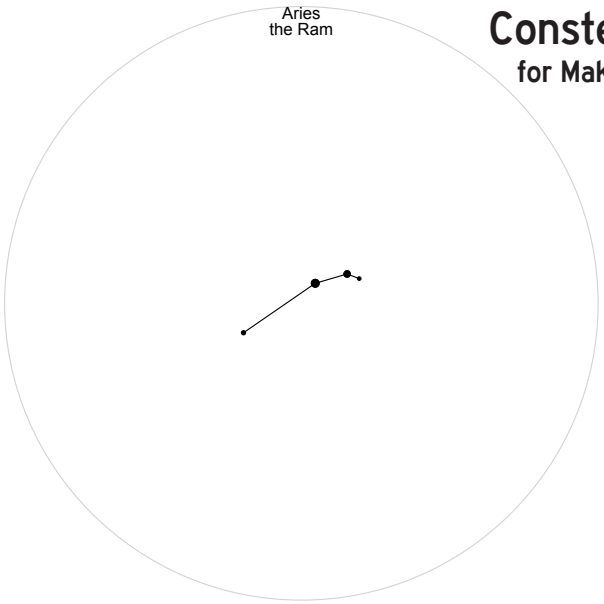
It takes commercial airplanes about 5 hours to cover that distance. Walking would take about 35 days with no sleep!

4,131 kilometers or 2,567 miles

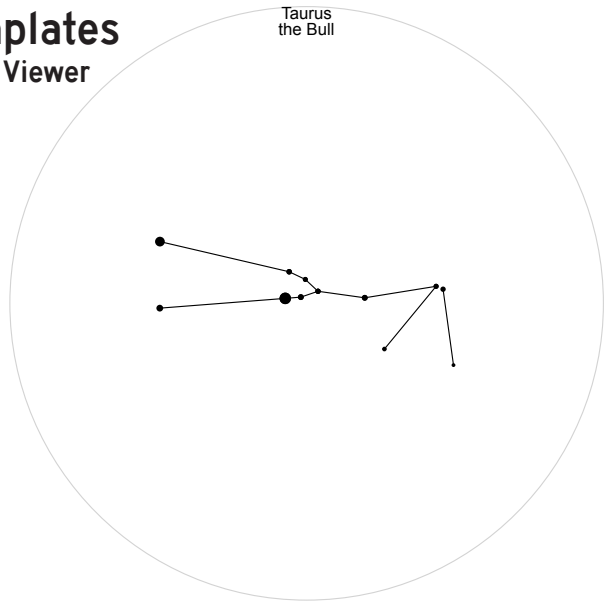
Constellation Templates

for Make a Constellation Viewer

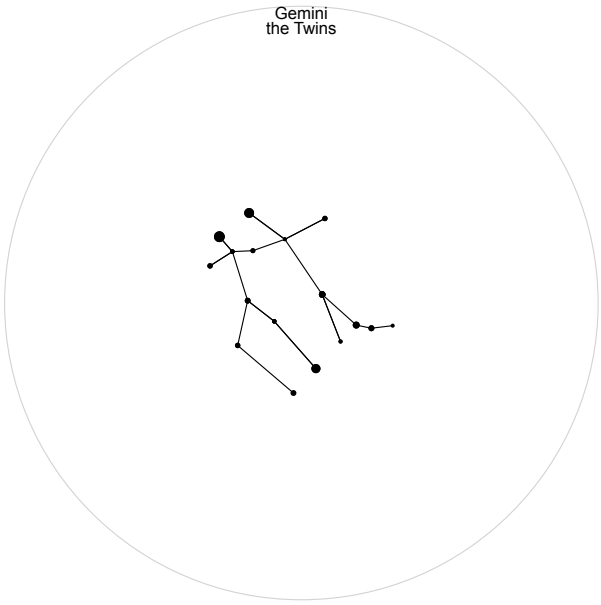
Aries
the Ram



Taurus
the Bull

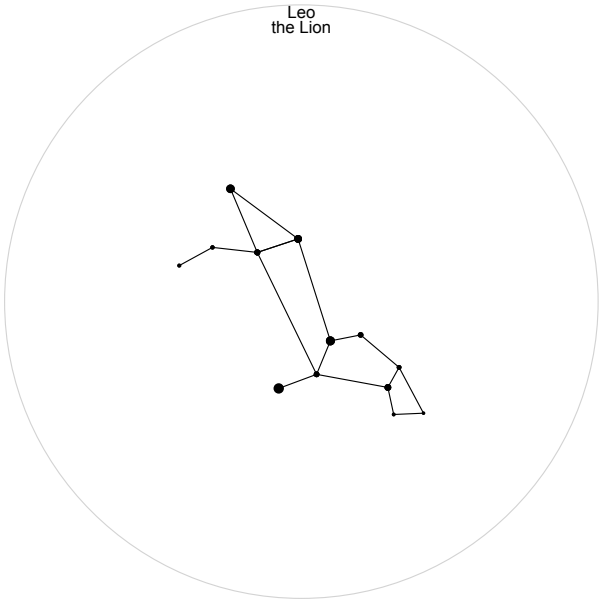


Gemini
the Twins

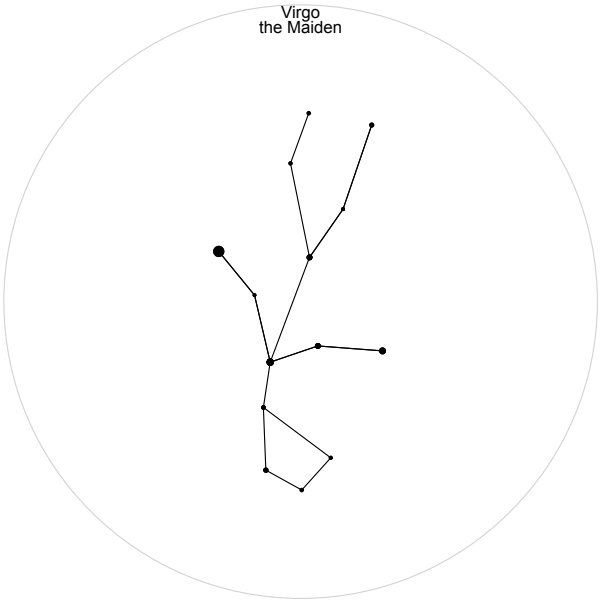


Cancer
the Crab

Leo
the Lion



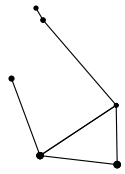
Virgo
the Maiden



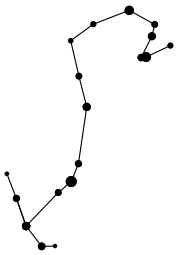
Constellation Templates

for Make a Constellation Viewer

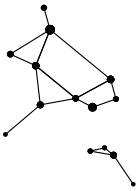
Libra
the Scales



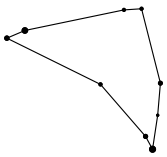
Scorpius5
the Scorpion



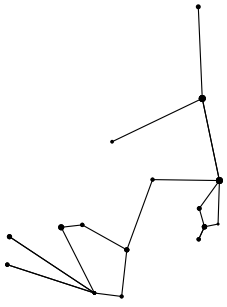
Sagittarius
the Archer



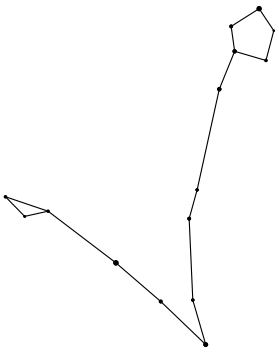
Capricornus
the Sea Goat



Aquarius
the Water Bearer



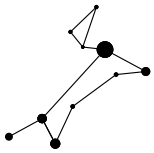
Pisces
the Fishes



Constellation Templates

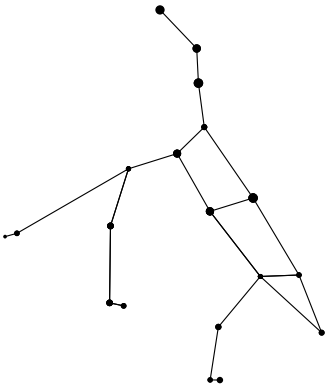
for Make a Constellation Viewer

Canis Major
the Great Dog

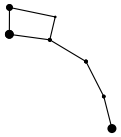


Crux
the Southern Cross

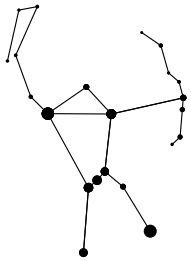
Ursa Major
the Great Bear



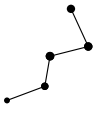
Ursa Minor
the Lesser Bear



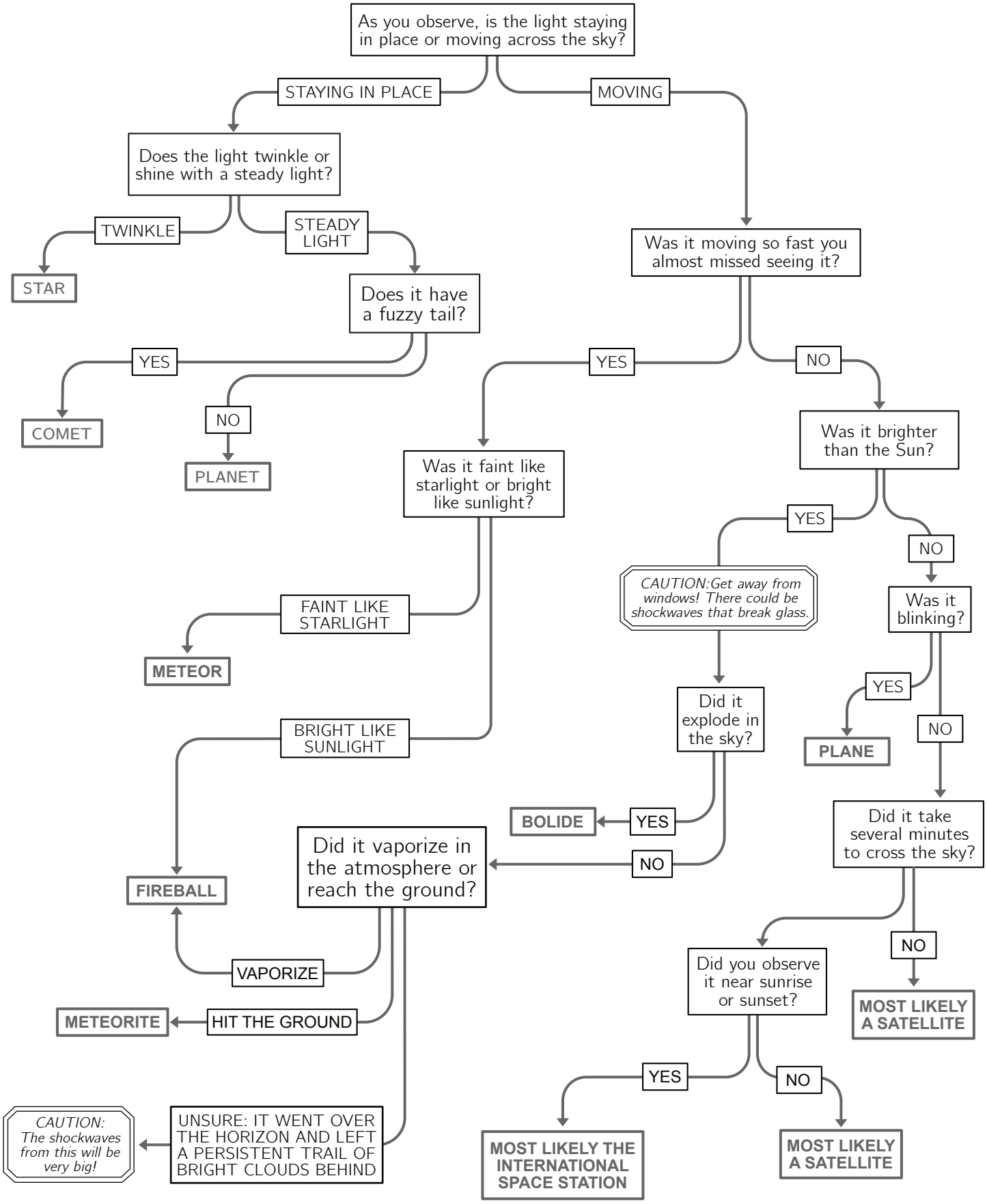
Orion
the Hunter



Cassiopeia
the Seated Queen

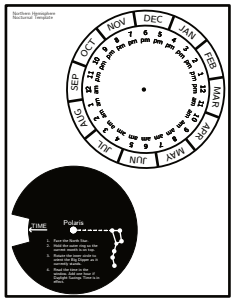


Night Sky Flowchart



CREATING A STAR CLOCK

MATERIALS



Nocturnal Handout

Scissors

Earring, tie pin, or other pin with backing

GOALS

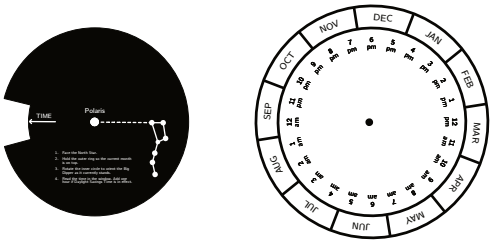
- Build a working star clock.
- Use the star clock to tell time

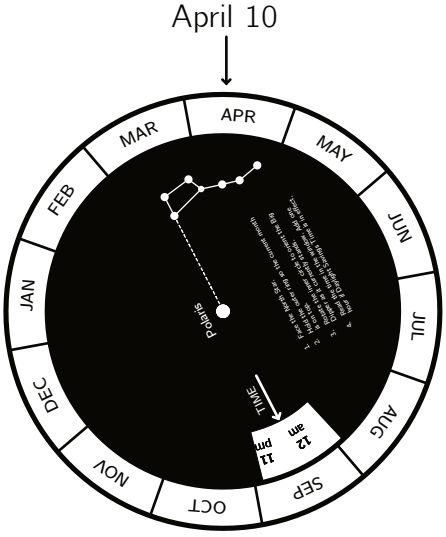
Tell the time with a Nocturnal

In this activity, you'll build a star clock called a nocturnal that will allow you to tell time by locating a constellation and orienting your nocturnal wheel to match the stars.

Instructions

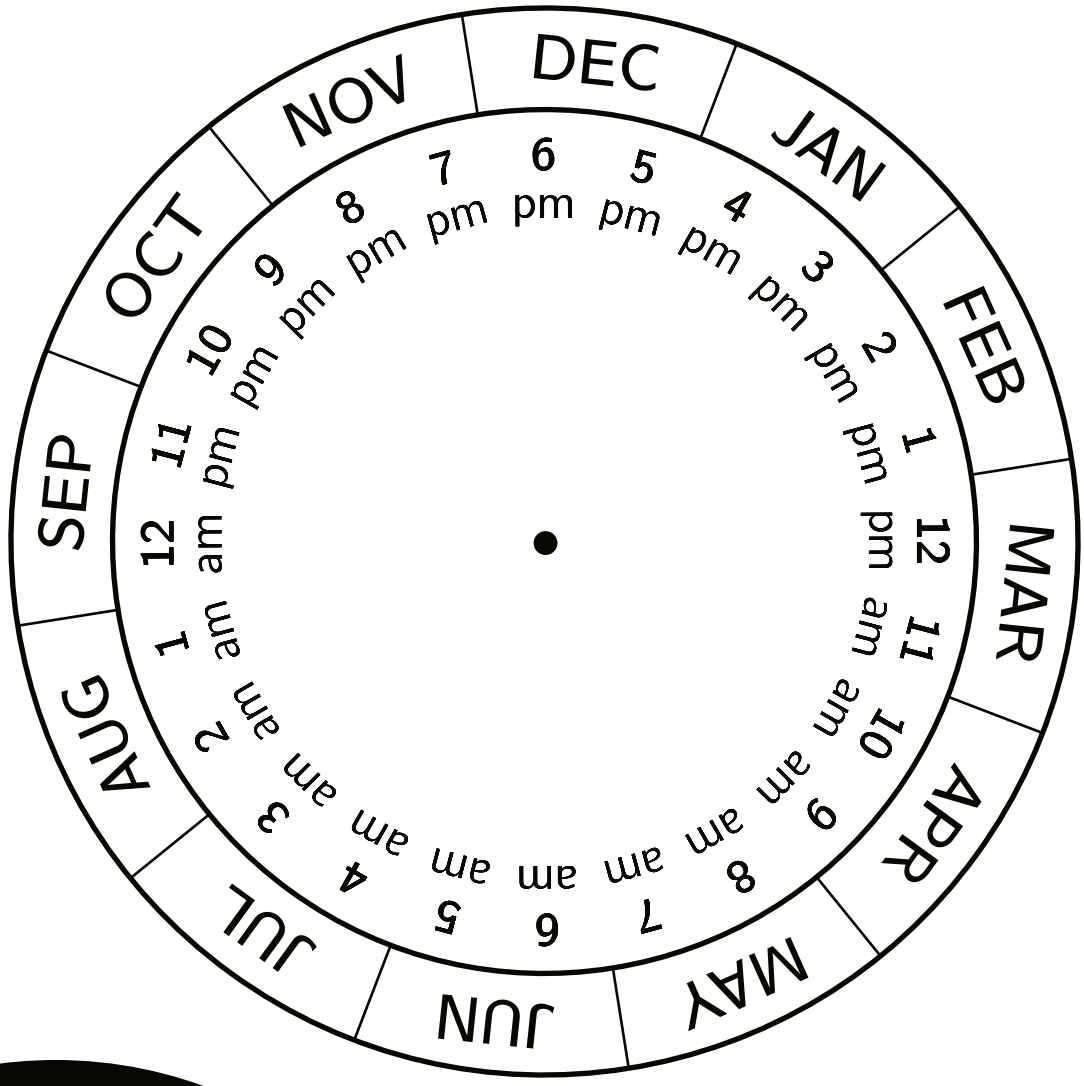
1. Cut out the two parts of the nocturnal from the template. Choose either the Northern Hemisphere template or the Southern Hemisphere template to match your location.
2. Poke a hole in the center of both discs separately, and then attach the black disc atop the white disc using the pin or earring to lock the discs together. You should be able to spin the discs separately.
3. Face straight north (or south).
4. Orient the white disc so that the current date is pointed straight up.
5. Locate the Big Dipper (or Crux) asterism.
6. Spin the black disc to match the asterism's location.
7. Read the time off the nocturnal. (Add one hour to the readout during daylight savings time.) In this example, the date is April 10 which is about a third of the way between March and May for the top of the white disc. The time indicated is between 11 pm and midnight, at about 11:45 pm. However, daylight savings time is in effect, so the time estimated by the nocturnal is 12:45 am.

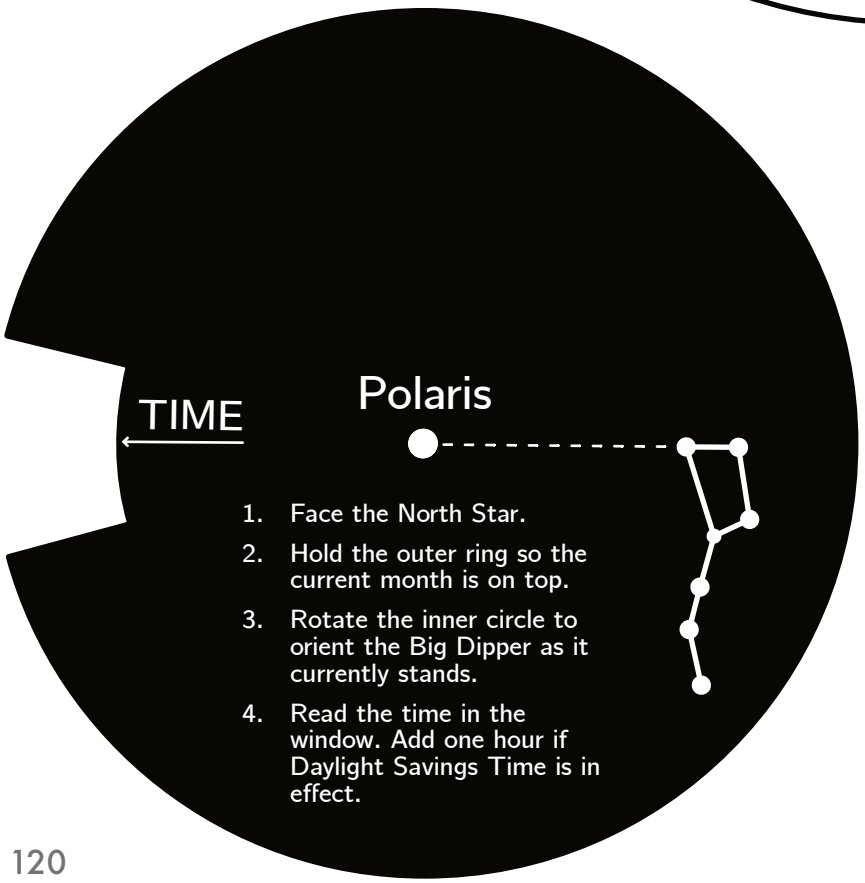




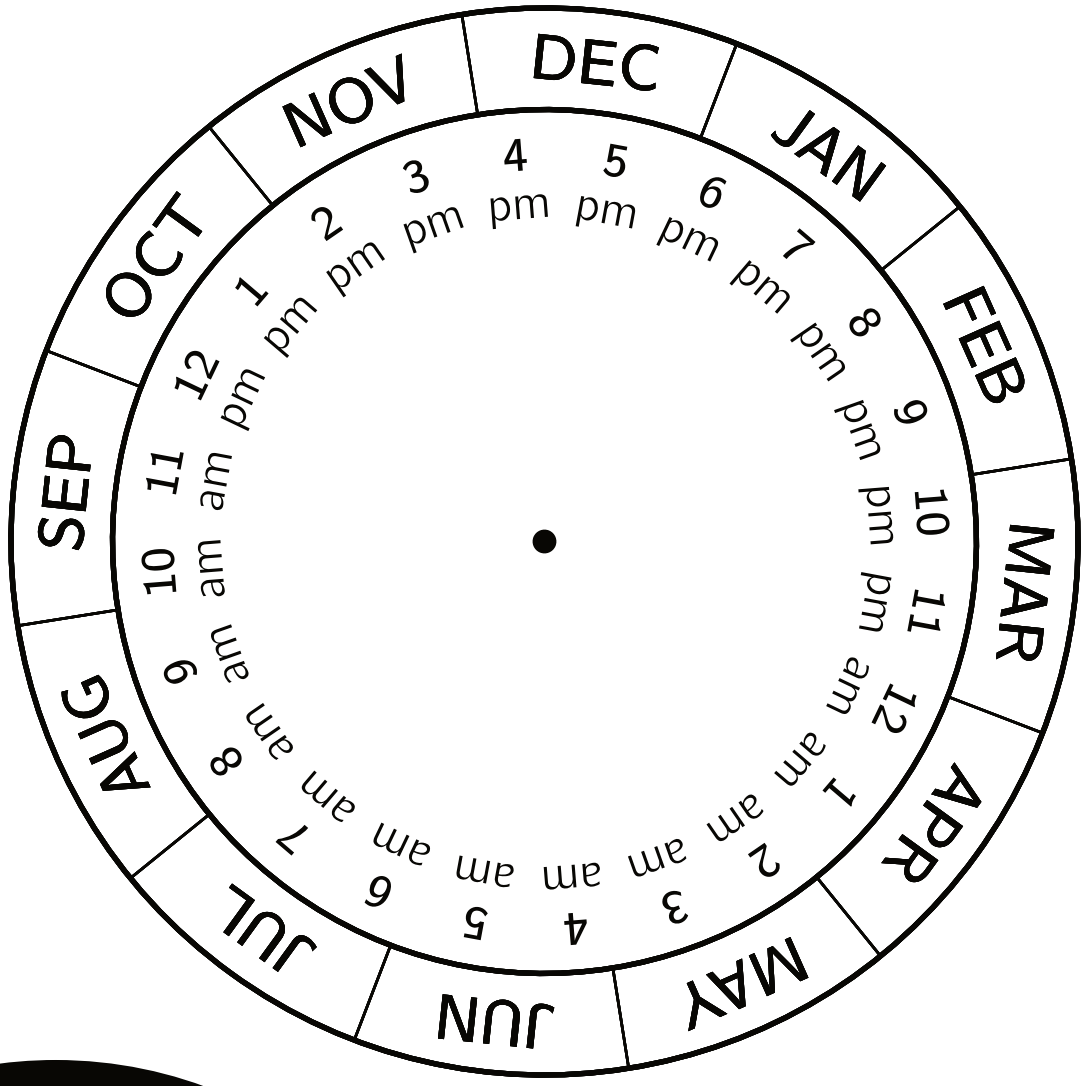
If you happen to live in the far eastern edge of your timezone, you might want to subtract 30 minutes from the time reading on the nocturnal. If you live on the far western edge of your timezone, you might want to add 30 minutes to the time estimate of the nocturnal.

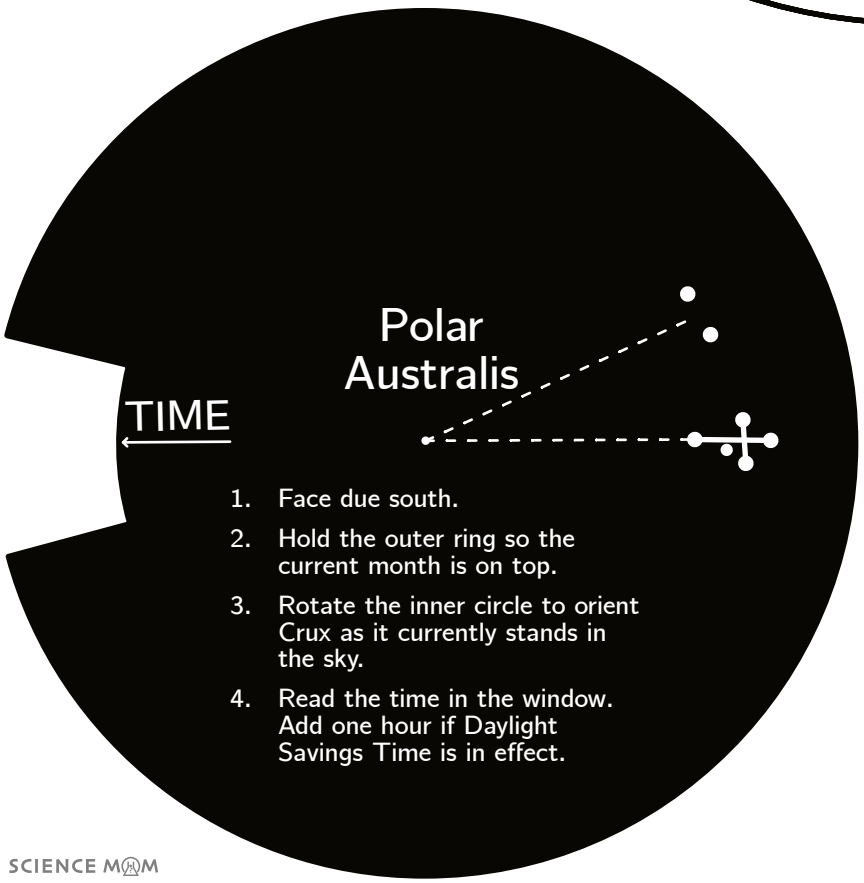
Northern Hemisphere
Nocturnal Template





Southern Hemisphere
Nocturnal Template





1. Face due south.
2. Hold the outer ring so the current month is on top.
3. Rotate the inner circle to orient Crux as it currently stands in the sky.
4. Read the time in the window. Add one hour if Daylight Savings Time is in effect.