Active Learning Tutorials for Astronomy & the Planetary Sciences

Preliminary Field-Test Edition

CAPER Center for Astronomy & Physics Education Research

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Preface for Students

You might think astronomy is about looking through a telescope on a chilly night high atop some lonely mountain summit. Or you might think instead that astronomy is about sitting in front of a super-fast computer using complicated mathematical formulas to make predictions about the fate of our Universe. Certainly, the study of astronomy can involve many different things, but at its core, astronomy is about wonder. Wondering about what the surface of distant planets are like, wondering about why some stars shine bright while others are dim, wondering how galaxies of stars first formed, and wondering if humans can live on planets orbiting other stars.

When you take an astronomy class, there will be many new names to learn and ideas to wrestle with. This book is designed to help you practice using those names and ideas in most effectively learning to wonder about how the Universe works. Each of the ACTIVE LEARNING TUTORIALS—or ALTs for short—challenges you to take the notions you are learning in class and from your readings, and to develop more meaningful and deeper understandings by applying those ideas in novel contexts. In other words, using ALTs will help you be a better "wonder-er" about astronomy.

These ALTs have been carefully designed to help you understand topics better instead of as an introduction. As it turns out, because these ALTs often use new vocabulary terms and representations, they are often difficult to do before you've had at least some introduction to the topic. In other words, if you've skipped the readings or didn't see the accompanying lectures, you might find these quite challenging to complete. On the other hand, these ALTs work great at enhancing your learning during reading breaks or during lecture breaks. Moreover, we've found that ALTs work best if you complete them with a classmate—not just comparing answers and checking each other's work, but actually working collaboratively on each and every question to be sure you understand and agree on both what the question is asking and what the more correct answer is. When you can, lean on the collective brains of a social group as learning can often best be done in small groups.

With this short introduction, we welcome you to wonder with us about the nature and inner workings of the Universe.

Preface for Instructors

Building on discipline-based astronomy education research on how people learn, each included ACTIVE LEARNING TUTORIAL—or ALT for short—takes into account and targets common misconceptions students have about astronomy and space science. Astronomy is the study of the *entire* Universe after all, and novice learners need guidance on how to make sense of it all.

These ALTs support students' thinking by providing the supportive cognitive frameworks they need to most effectively wrestle with new ideas while helping students keep from getting overwhelmed. Each ALT is short, requiring only 5-7 minutes of time, and focusing on a single aspect of an overarching idea. At the same time, these ALTs rely heavily on illustrations and are written to be effective with students who haven't yet become strong textbook readers and those who may not yet be completely fluent in English as their first language.

In order for students to "think," they first have to know something. These ALTs are not designed to be used in the absence of lecture or reading; rather, they are best used as a supplement to your teaching. They provide students with extended experiences and engagement in astronomy so that they can deepen their understanding and retain the ideas longer

When used in a supportive learning environment, these ALTs will help the widest possible diversity of students learn astronomy. Most instructors use the ALTs during class time to break up their lecture by asking students to come to consensus answers while working in small learning groups.

We have had great success using ALTs with students and fellow faculty in helping break up lectures to better and more actively engage students in the doing of astronomy. We hope you will too! Within this text, errors most certainly exist, and we would very much appreciate knowing about them so we can fix them in future printings. The science of astronomy is, after all, a collective human enterprise, and our greatest wish for our community of astronomy educators is to join together and help each of us do a better job of sharing the wonders of the Universe with our students.

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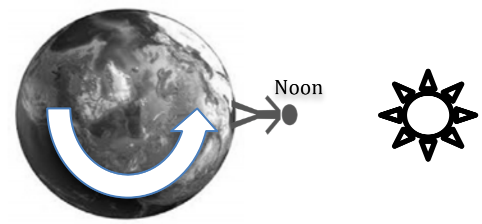
Motions in the Sky

Nightly Movement of the Stars 1

As Earth spins on its axis, the Sun, Moon, stars and everything beyond Earth appears to move across the sky. When thinking about observing the sky from a spinning Earth, it usually easiest to imagine a counter-clockwise spinning Earth as seen from above its North Pole.

The Figure at right illustrates an observer at the equator at noon as seen from above.



1. Sketch and label the position of the observer at 6pm, midnight, and 6am.

2. The brightest star in the constellation of Orion is the star called Rigel. On the Figure above label where the very distant star Rigel must be when it is seen high in the sky at midnight.

3. Sketch and label the position of the Moon, when it is high above an observer's head, at sunrise.

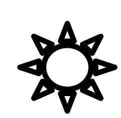
4. Objects in the sky appear to rise and set because Earth spins on its axis. If a star rises in the East on at 8:00 P.M. on a Monday night, how many hours must pass before it rises again?

Circle One: About 6 hours About 12 hours About 24 hours

5. If Earth was spinning two times faster, only taking about 12 hours to spin once, how long would it take for a star to appear to move across the sky from Eastern to Western horizon?

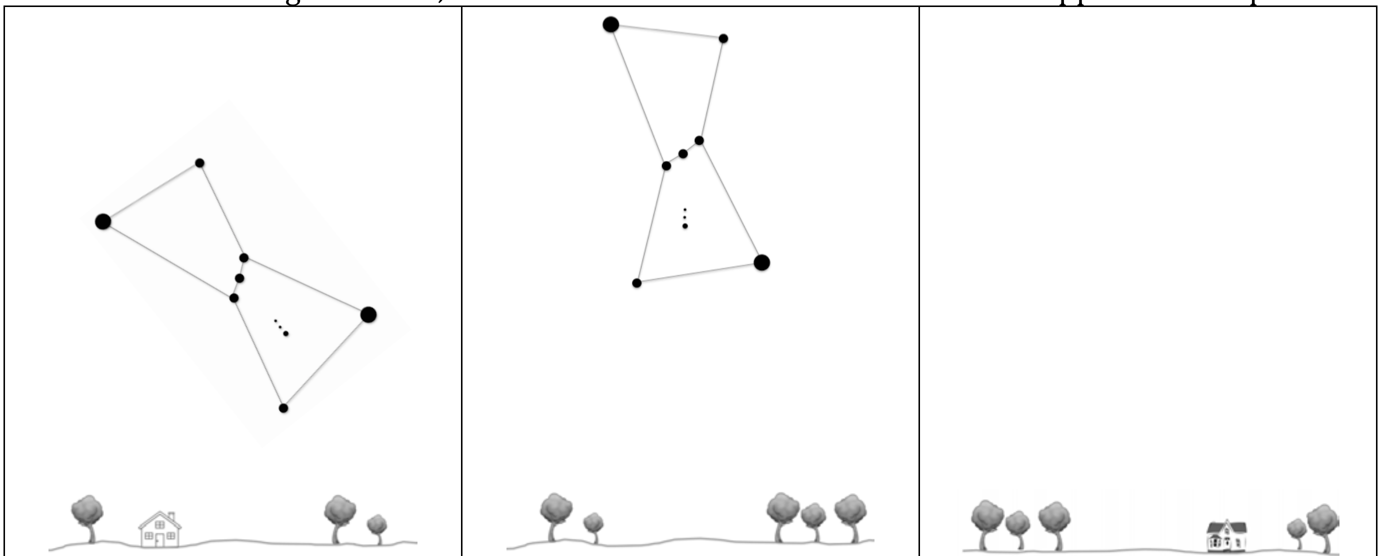
Circle One: About 6 hours About 12 hours About 24 hours

6. In the space below, redraw the TOP-VIEW Figure instead as a SIDE-VEW to show why an observer on the equator can only see the Sun during the day, but a different observer at the North Pole can sometimes see the Sun anytime. *Use arrows and labels to help explain your drawing*.



Although the spinning Earth causes the Sun and stars to appear to move, the brain tends to find it easier to imagine that the Earth is not moving at all, and that it is the Sun and stars that are moving, drifting across the sky from East to West.

7. As seen from Earth's surface, most objects in the sky seem to move from East to West. In the third frame of the figure below, draw how the constellation of Orion would appear about 6pm.

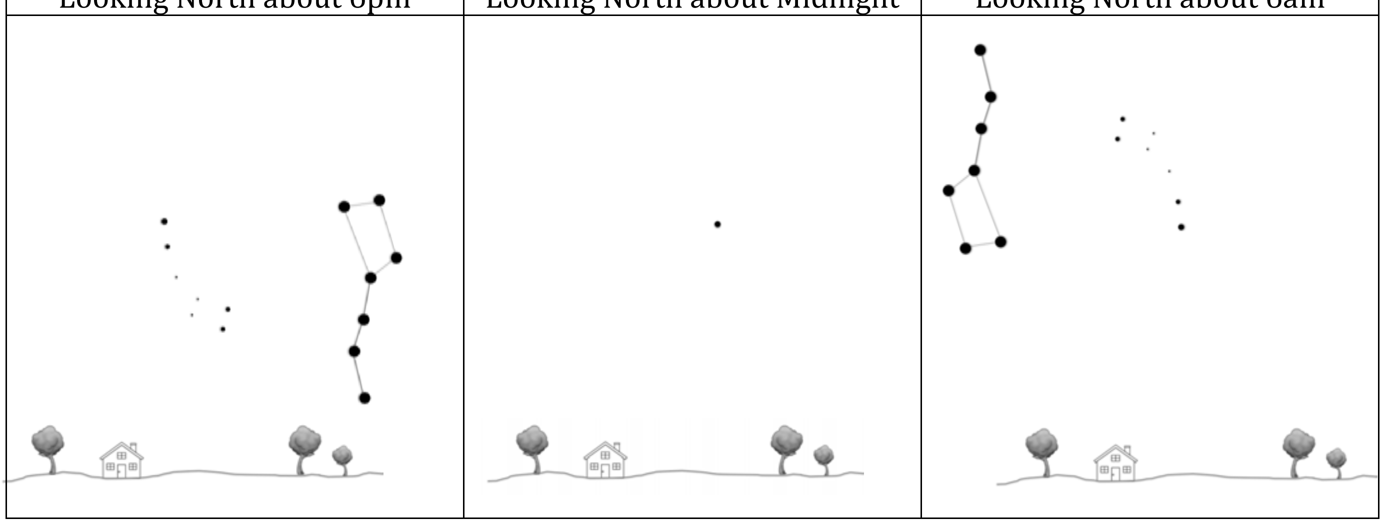


Looking East about 6pm	Looking South about Midnight	Looking West about 6am

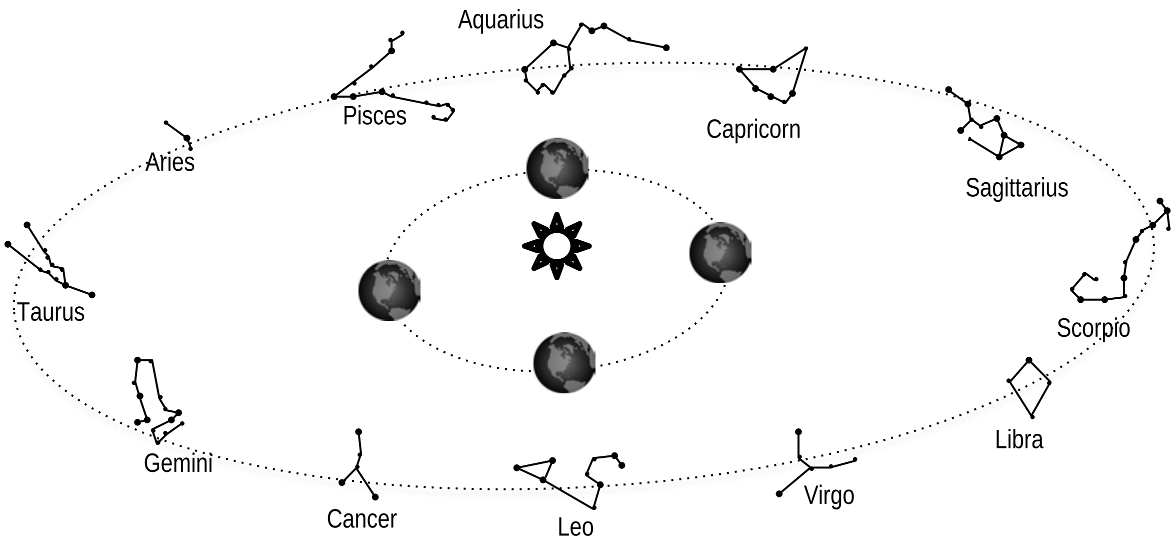
8. The brightest star in the constellation of Orion is called Rigel. It is the brightest star on the right hand side. Label Rigel in the Figure above.

9. From the mid-latitudes of the Northern hemisphere, the seven stars of the Big Dipper never appear to rise and set, but move around the North Star (Polaris) counter-clockwise. Below, label the North Star (Polaris), and draw how the Big and Little Dippers appear in the middle frame.

Looking North about 6pm	Looking North about Midnight	Looking North about 6am



When looking toward the southern horizon, different stars are seen at different times of the year. For example, Gemini and Cancer are prominent constellations in the winter sky, while Scorpio and Sagittarius dominate the summer's midnight sky.



1. Taurus is a constellation often seen in the winter night sky. Draw a stick figure observer on Earth, where Taurus can be seen overhead in the midnight sky.

2. One month later, Gemini is most easily seen at midnight. Then a month after that, Cancer is most easily seen at midnight. Which constellation is most easily seen at midnight one month later, in early March?

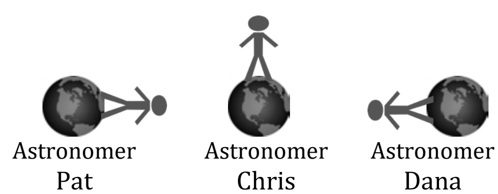
Circle One: Taurus Gemini Leo Scorpio Aquarius

3. On the figure, draw arrows indicating which direction Earth is orbiting around the Sun AND which way Earth is spinning.

4. Which constellation can NOT be seen in early March, because the brilliantly shining Sun is blocking it from view?

Circle One: Taurus Gemini Leo Scorpio Aquarius

5. Imagine three astronomers are arguing about how to correctly sketch an overhead view showing the position of an observer at SUNSET for Earth's position in March for the above Figure. Which proposed position at right do you agree with, and why? *Explain*.



6. The North Star can be seen any time of the year. Mark is the position of the North Star (Polaris) on the top figure?

For each of the 12 months of a year, there is a constellation that is the primary midnight constellation, and a constellation that is overhead at noon, and entirely blocked from our view by the brilliantly shining Sun.

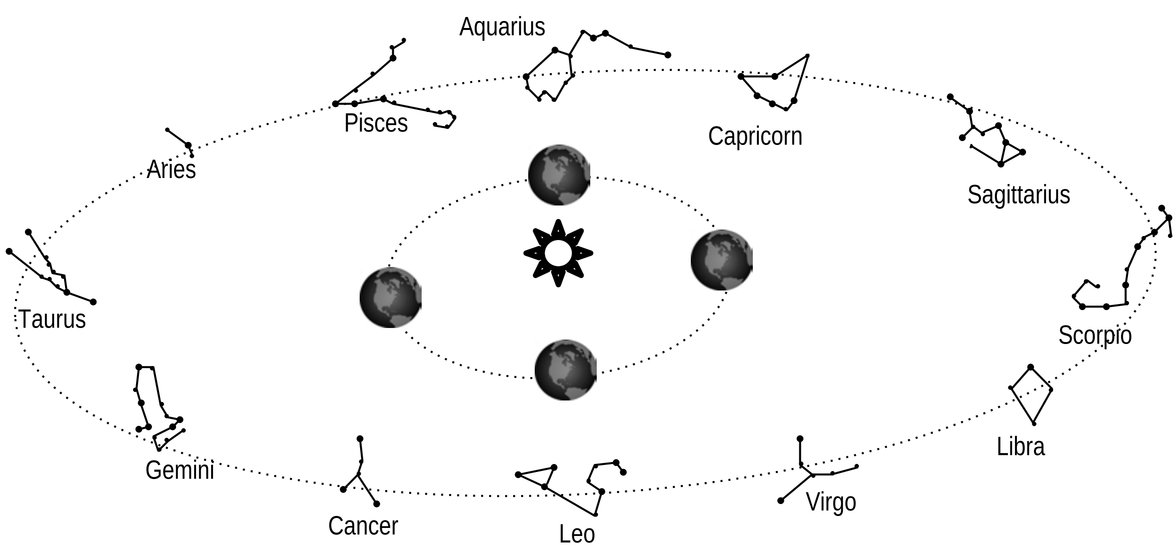
Over 2000 years ago, the "sun-blocked" constellations were arranged into a calendar based upon when they are overhead at noon, and are still known today as the "signs of the zodiac." Sometimes people have heard about zodiac horoscope constellation signs being assigned to them by the date of one's birth. The zodiac calendar of 160 B.C. is listed in the table below.

Dates	Horoscope Sign	Sun-Blocked in 160 BC	Sun-Blocked in 2016 AD
January 20 – Feb. 18	Aquarius	Aquarius	Capricorn
February 19 – March 20	Pisces	Pisces	Aquarius
March 21 – April 19	Aries	Aries	Pisces
April 20 – May 20	Taurus	Taurus	Aries
May 21 – June 20	Gemini	Gemini	Taurus
June 21 – July 22	Cancer	Cancer	Gemini
July 21 – August 22	Leo	Leo	Cancer
August 23 – Sept. 22	Virgo	Virgo	Leo
September 23 – Oct. 22	Libra	Libra	Virgo
October 21 – Nov. 21	Scorpio	Scorpio	Libra
November 22 – Dec. 21	Sagittarius	Sagittarius	Scorpio
November 29 – Dec. 18	*Sagittarius*	*Sagittarius*	*Ophiuchus*
December 22 – Jan. 19	Capricorn	Capricorn	Sagittarius

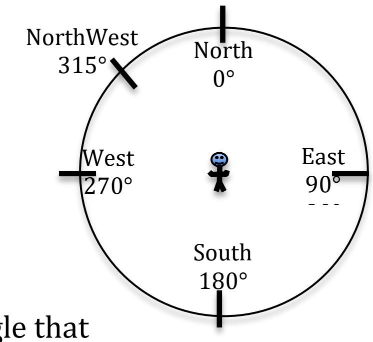
There are two interesting things to notice. One is that the constellation blocked by the Sun for any given date has changed over the past 2000 years. The second interesting thing is that there is a thirteenth constellation. Between the dates of November 19^{th} and December 18^{th}, the constellation *Ophiuchus* is hidden by the noon Sun. These changes have occurred because Earth's orbit around the Sun has drifted slightly over the last several thousand years. The real location of the constellations and the original zodiac calendar have been out of alignment for many years.

7. Which constellation was blocked by the Sun on your birthdate, in 160 B.C.? In 2016 A.D.?

8. On the figure below, label the Earth's position on September 5, 2016 AND label the position of Ophiuchus.



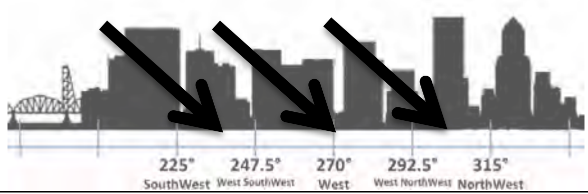
Follow the Setting Sun 3



Some people think that the Sun always rises directly in the East and sets directly in the West. With more careful observation, we can see that the Sun's precise rising and setting position changes dramatically over the course of a year.

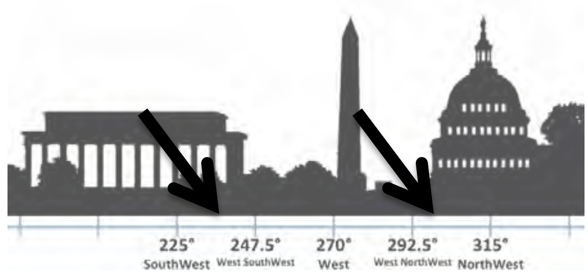
Precisely Measuring Directions: In astronomy, we pin-point specific directions as if the horizon were a giant 360° circle where the direction North is 0°, East is 90°, South is 180°, and West is 270°.

1. The following table gives the direction of the setting Sun and the angle that the Sun's path makes with the horizon. Complete the table showing the direction the Sun is setting, the angle the Sun's pathway makes with the horizon, and sketch an arrow indicating it's pathway.



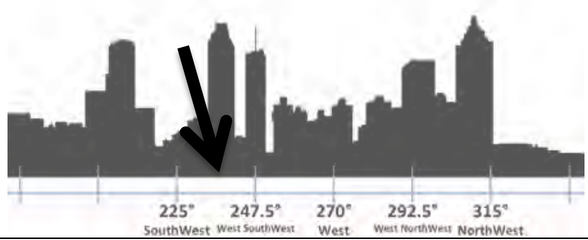
Portland, Oregon (Latitude 45°)

Date	Direction	Horizon Angle
December 21	235°	45°
March 21	270°	45°
June 21	305°	45°
September 21		



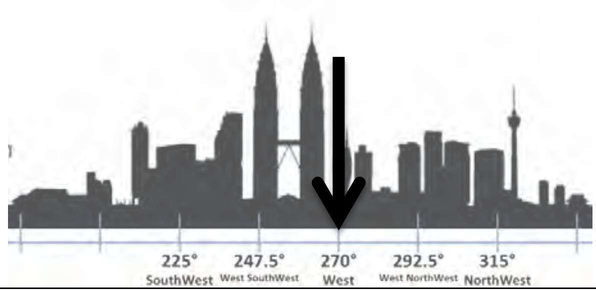
Washington, DC (Latitude 39°)

Date	Direction	Horizon Angle
December 21	240°	51°
March 21		
June 21		51°
September 21	270°	



Atlanta, Georgia (Latitude 33°)

Date	Direction	Horizon Angle
December 21	240°	
March 21		
June 21	300°	
September 21		57°



Kuala Lumpur, Malaysia (Latitude about 0°)

Date	Direction	Horizon Angle
December 21		90°
March 21		
June 21	293°	
September 21		

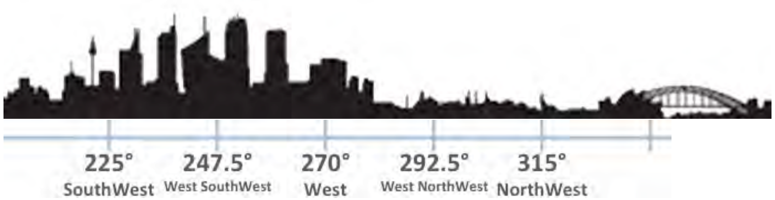
2. What angle does the Sun's pathway make with the horizon, for cities along Earth's equator?

3. How does the angle of the Sun's pathway with the horizon change as one observes from latitudes farther and farther north?

4. How many degrees along the horizon does the Sun move for a city at 39° latitude over a six month period?

5. Predict the Sun's position and setting angle with the horizon, at sunset for your birthday, for the city closest to your latitude.

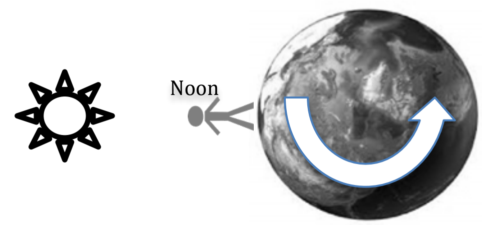
6. Below is the skyline for Sydney, Australia at 33° South latitude. Predict the horizon position and pathway for the setting Sun.



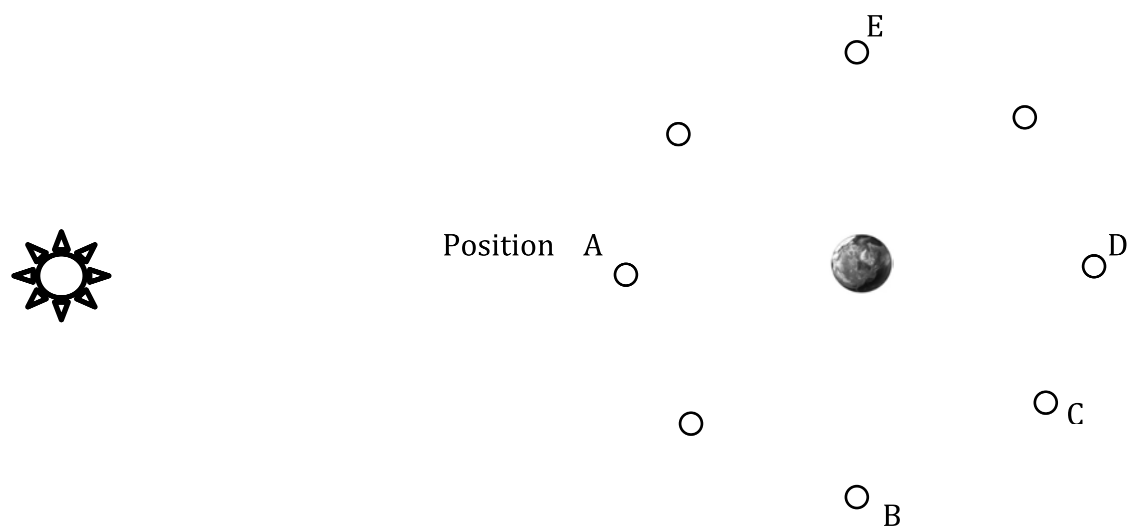
You might have noticed that the cities at 45° and above start to experience more extreme changes. Above 45° North—and below 45° South—the seasonal changes make these position estimates difficult to do without a calculator. These changes become so extreme that North of the Artic circle—and South of the Antarctic Circle—there are winter days where the Sun never actually sets.

The Moon appears differently each night because we are seeing differing amounts of its ½ illuminated side. The time it appears in the sky, and where in the sky it is, depends on the relative positions between the Sun, Earth, and Moon.

The Figure at right illustrates an observer at the equator at noon as seen from above.



1. Sketch and label the position of an observer at sunset, midnight, and sunrise on the figure below (*not the one at right*).



3. Refer to the figure above to answer the following questions. If the Sun and Moon are on opposite sides of Earth (position D), what time does the Moon appear highest in the sky?

C*ircle one*: Noon Sunset Midnight Sunrise

4. If the Moon is at position D, what time can an observer on the spinning Earth first see the Moon rising above the horizon?

C*ircle one*: Noon Sunset Midnight Sunrise

5. If the Moon is at position D, what time can an observer on the spinning Earth see the Moon setting below the western horizon?

C*ircle one*: Noon Sunset Midnight Sunrise

6. The moon is visible in the sky for about 12 hours as the Earth turns underneath it. If the Moon is first visible at Noon (position B), then what time will it be highest in the sky (over the observer)?

C*ircle one*: Noon Sunset Midnight Sunrise

7. If the Moon is first visible at Noon (position B), then what time will it disappear from view (set)?
C*ircle one*: Noon Sunset Midnight Sunrise

When wondering about the Moon at position D—with the Earth between the Sun and Moon—our brain naturally jumps to the conclusion that we won't be able to see the Moon because it is in Earth's shadow. Your brain is right; however, only rarely is the Earth DIRECTLY between. Most often, the Moon at position D is slightly above or below Earth's shadow.

8. How much (what fraction) of the Moon's surface is illuminated when it is at each position?	Moon's Position	Fraction of Moon's Surface Illuminated by Sun	Sketch Appearance of Moon from Earth	What time does the Moon rise?
	A			
	B			
	C			
	D			
	E			

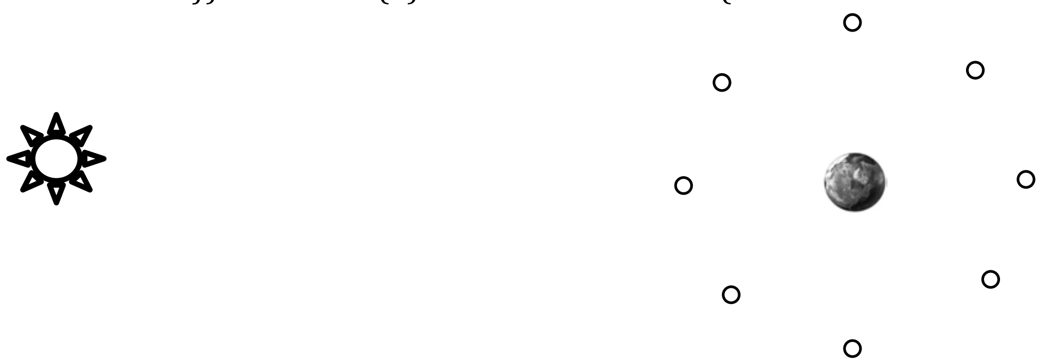
8. Two astronomers are arguing about what time the full moon can be seen.

> *Astronomer Pat*: The full moon occurs when the Moon is on the opposite side of Earth from the Sun. The full moon rises when the Sun sets and then sets with the Sun becomes visible.
>
> *Astronomer Chris*: That doesn't make any sense. Each night, the Moon starts out as a thin sliver on the Eastern horizon and is full by the time it sets.

With which astronomer do you agree with and why? *Explain*.

Eclipses are rare events where the shining Sun is blocked by our Moon for a few minutes or when Earth blocks sunlight from illuminating the full moon for a few hours. Let's consider which positions of the Sun, Moon, and Earth allow for eclipses from an overhead, top-view perspective.

1. The figure below shows various positions of the Moon orbiting Earth as seen from above, called a top-view. LABEL the positions where (i) a FULL MOON occurs (*when people on Earth can see the entire sunlit half*) and where (ii) a NEW MOON occurs (*where we cannot see any of the sunlit half*).



2. The table below lists the dates of the moons for 2015. Why does the full moon look different on April 4 and September 28, when a lunar eclipse is occurring?

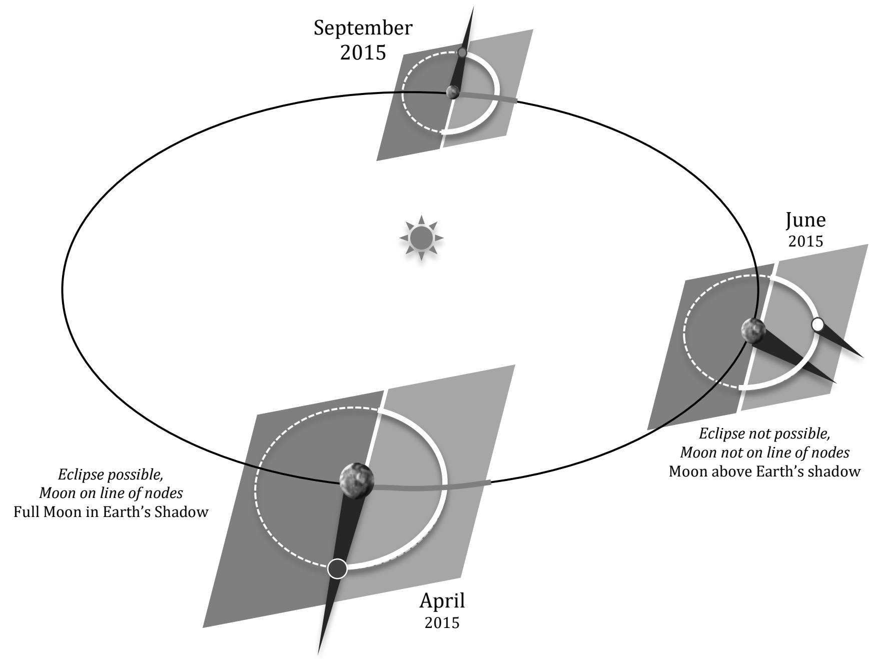
Full Moon Dates	Feb 18	Mar 5	Apr 4 Eclipse	May 4	June 2	July 2	July 31	Aug 29	Sep28 Eclipse	Oct 27	Nov 25	Dec 25

3. Describe what is happening with the Sun, Moon, and Earth on these other dates, that is *NOT* happening April 4, 2015 and September 28, 2015?

Your brain really wants monthly moon phases to be caused by Earth blocking sunlight from hitting the Moon, but moon phases are instead caused by how much of the lit side of the Moon we can see from Earth. HOWEVER, in this rare case of eclipses, the blocking of sunlight really is what is happening, and you should congratulate your brain for its correct thinking!

The figure below shows how the plane of the Moon's orbit around Earth is tilted with respect to the plane of Earth's orbit. This causes the Moon to sometimes be above the plane of Earth's orbit—and sometimes below. The Moon's orbit is tilted about 5° from Earth's orbit.

4. In the space at below, describe how the position of the Full Moon is different on June 2, 2015 compared to its different position three months later on September 28, 2015?



5. The figure below shows side-view (cross-section) sketches of the Moon's position on March 4, 2015. In the space provided, draw the Moon's position on July 2 and December 25, 2015.

March 4, 2015	July 2, 2015	December 25, 2015
Side-View		

6. Consider the discussion between two astronomers.

Astronomer Pat: Eclipses occur every month when Earth gets between the Sun and Moon, but we can't often see it because it happens on the other side of the Earth from where we are.

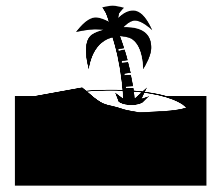
Astronomer Chris: I disagree. I think eclipses only occur in some months because the Moon's orbit is inclined and doesn't often perfectly line up with Earth's orbit.

With which astronomer do you agree with? (*Circle one*) Pat Chris

7. What is the likelihood of getting a lunar eclipse on the Full Moon of March 23, 2016? Explain your reasoning by referring to the Figure in Question 4 above. *Make sketches if necessary*.

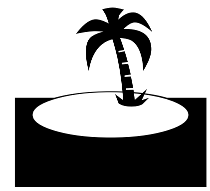
Earth’s Tides 6

Most coast lines on Earth experience two high tide periods every day, about 12 ½ hours apart. A high tide period is where the ocean reaches its highest level on to the land. This is followed by the ocean level falling to lower and lower levels until it barely comes on to the land at all, called low tide. Low tide occurs about 6 ¼ hours after high tide. Then, the process reverses itself and the ocean moves toward a high tide period.



High Tide

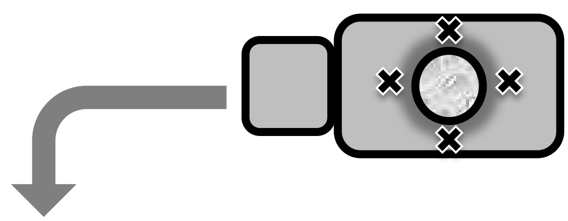
If you think that this might have something to do with the Moon, which passes overhead about every 12 hours and 51 minutes, you’d be right!



Low Tide

1. The figure at right shows a truck carrying a giant fishbowl full of water. If the truck is driving in a straight line then suddenly stops, which of the two people will get wet when the water sloshes out? (*circle the person*)

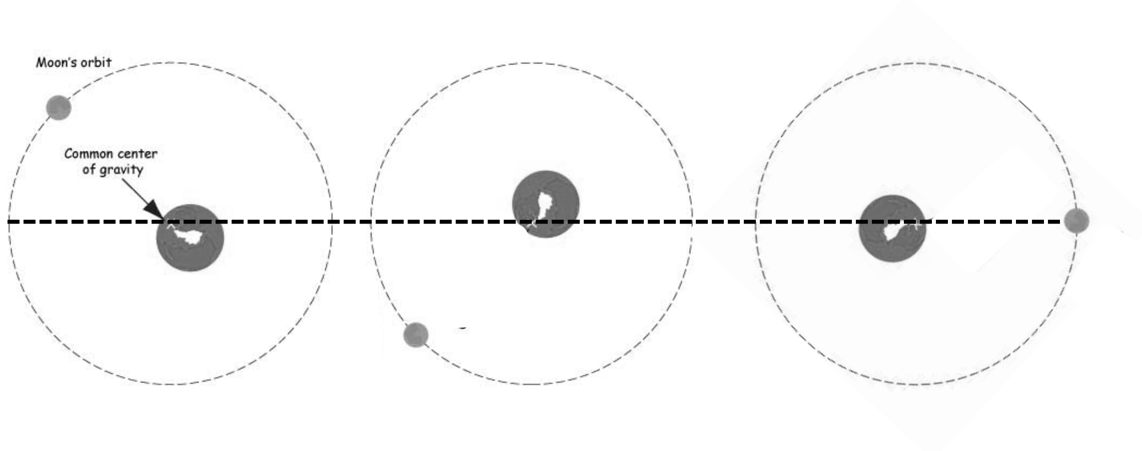
2. The next figure shows an overhead view of another truck quickly turning a corner. This truck also carries a giant fish bowl of water, and four people stand around the bowl on spots marked with an “×”. Of the four people shown standing around the water-filled bowl, who gets wet? (*circle the person*)



3. The general principle used to figure out where the water goes is called *INERTIA*. Create a definition of *INERTIA* in your own words in the space below.

Let’s consider our Earth and Moon. As it turns out, gravitational attraction causes the Moon to pull on Earth, just like Earth pulls on the Moon. The end result is that Earth swings back and forth with the Moon’s orbit, as illustrated on the next page, around a common center of mass.

4. On the figure below showing a top-view of the Moon orbiting Earth, sketch a small bulge where Earth's water is sloshed outward by inertia as the Moon and Earth twirl around.



5. At the same time on the other side of Earth, the gravitational attraction between the Moon and water on Earth nearest the Moon causes another bulge of water to lift upward away from Earth's surface. Sketch in this second bulge on the figure above.

6. Two astronomers are discussing the frequency of high tides on Earth.

> *Astronomer Pat*: If there are two tidal bulges on Earth—one on the side nearest the Moon and one on the opposite side farthest from the Moon—that means that everywhere on Earth experiences two high tides each month as the Moon orbits Earth.
>
> *Astronomer Chris*: I disagree. The Moon takes an entire month to orbit Earth, but while this is going on, Earth is very quickly spinning on its axis every day, spinning about 30 times in one month. That means that Earth spins underneath the tidal water bulges, passing through one about every 12 hours—or twice a day.

With which astronomer do you agree with? *Circle one*: Pat Chris

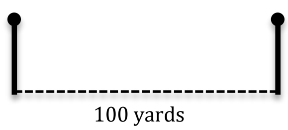
7. The high-tide-to-low-tide-to-high-tide cycle takes about 12 hours and 25 minutes. Why isn't this cycle precisely 12-hours long?

8. Pluto spins about once every 6 days and has a large moon that orbits also in about 6 days. What would tides be like on Pluto if it had them? *Use sketches to illustrate your answer.*

Physics of the Universe

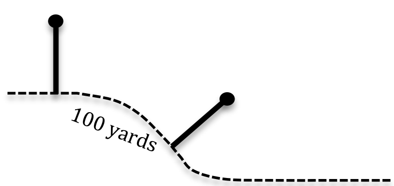
The first person credited with a reasonable measurement of Earth's size is the Greek mathematician Eratosthenes, in the 3rd Century B.C. His strategy was to measure the difference between two shadows cast at the same moment, but at different locations on Earth.

1. Imagine two flagpoles at opposite ends of a football field. Draw the two shadows cast by the poles if the distant Sun is at an altitude of 45°.

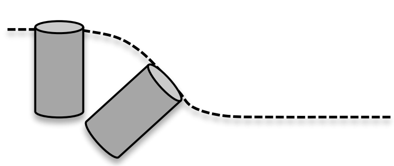


2. If you noticed a friend drawing the shadow for the right-side post much longer than the left-side pole, how would you correct their drawing?
Circle One:
(i) No change, the right-side shadow should be much longer
(ii) Make both shadows the same size as the pole

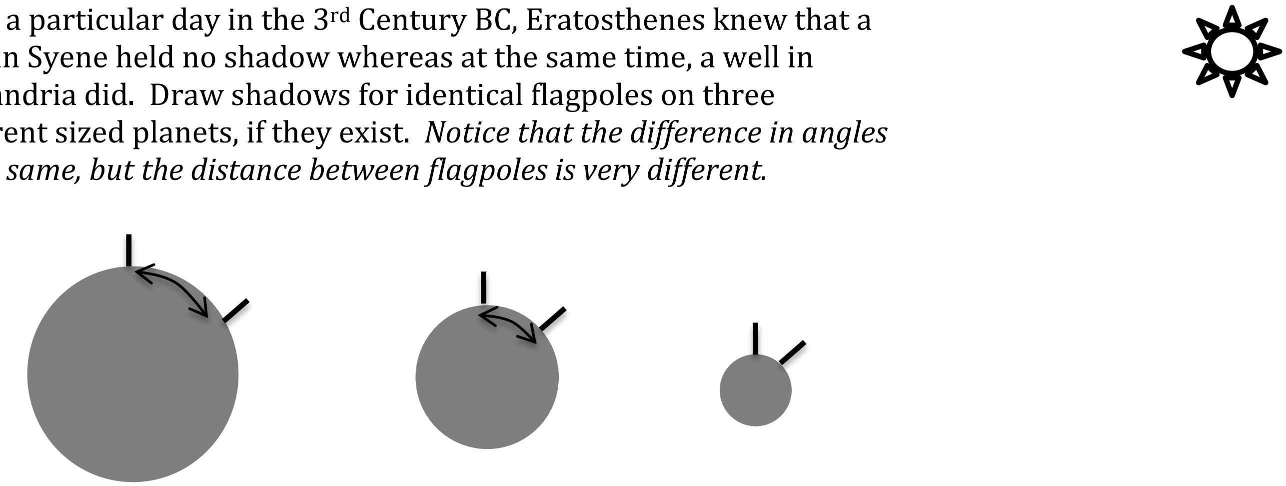
3. Imagine, these flagpoles were instead positioned on a hill.
Sketch the shadows the two flagpoles would make in this new situation.



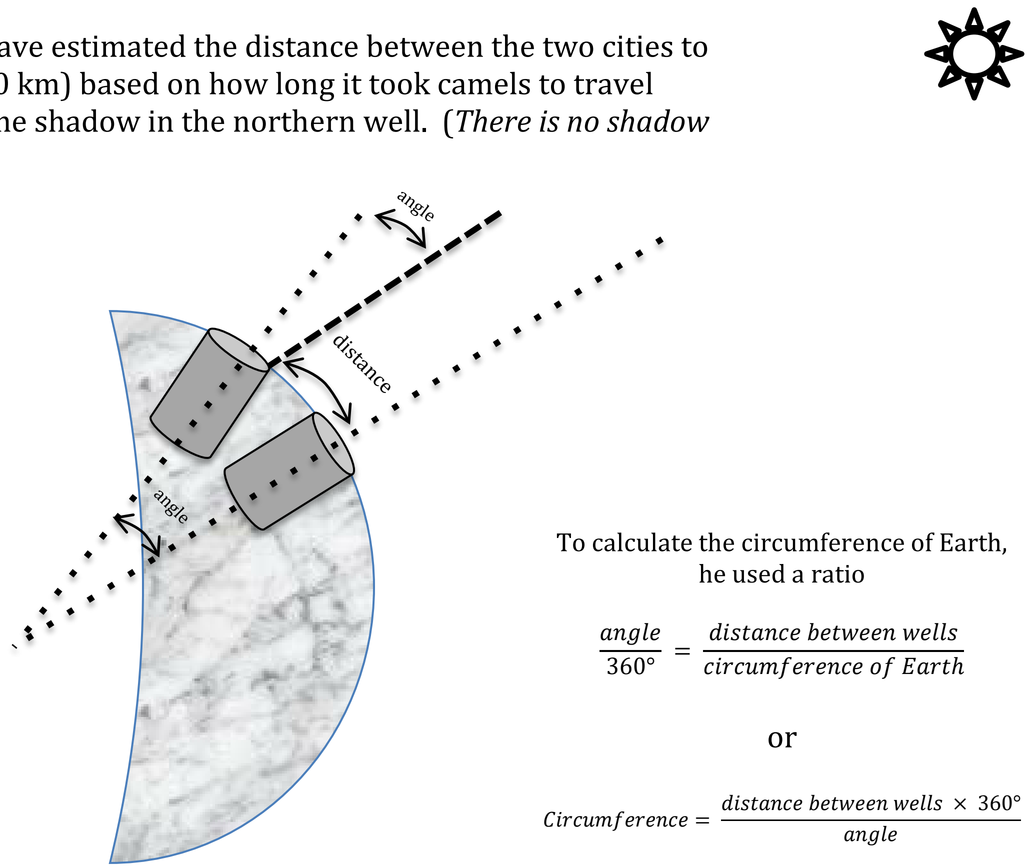
4. Now, let's consider water wells dug into the ground, instead of flagpoles.
Sketch how sunlight would penetrate into the wells, lighting portions of the well, and leaving other parts in shadow.



5. On a particular day in the 3rd Century BC, Eratosthenes knew that a well in Syene held no shadow whereas at the same time, a well in Alexandria did. Draw shadows for identical flagpoles on three different sized planets, if they exist. *Notice that the difference in angles is the same, but the distance between flagpoles is very different.*



6. Eratosthenes could have estimated the distance between the two cities to be about 500 miles (800 km) based on how long it took camels to travel between them. Draw the shadow in the northern well. (*There is no shadow in the southern well*).



To calculate the circumference of Earth, he used a ratio

$$\frac{angle}{360°} = \frac{distance\ between\ wells}{circumference\ of\ Earth}$$

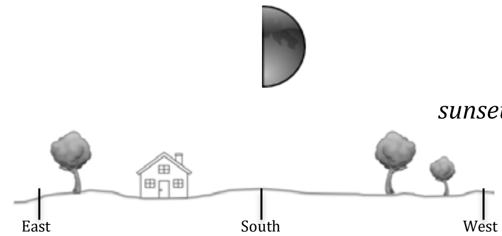
or

$$Circumference = \frac{distance\ between\ wells \times 360°}{angle}$$

7. 🖩 Eratosthenes' estimated the angle at 7.2°, and the distance to be 500 miles (800 km). Use a calculator and determine Earth's circumference and compare with the size of Earth we know today, 7,918 miles (12,742 km)?

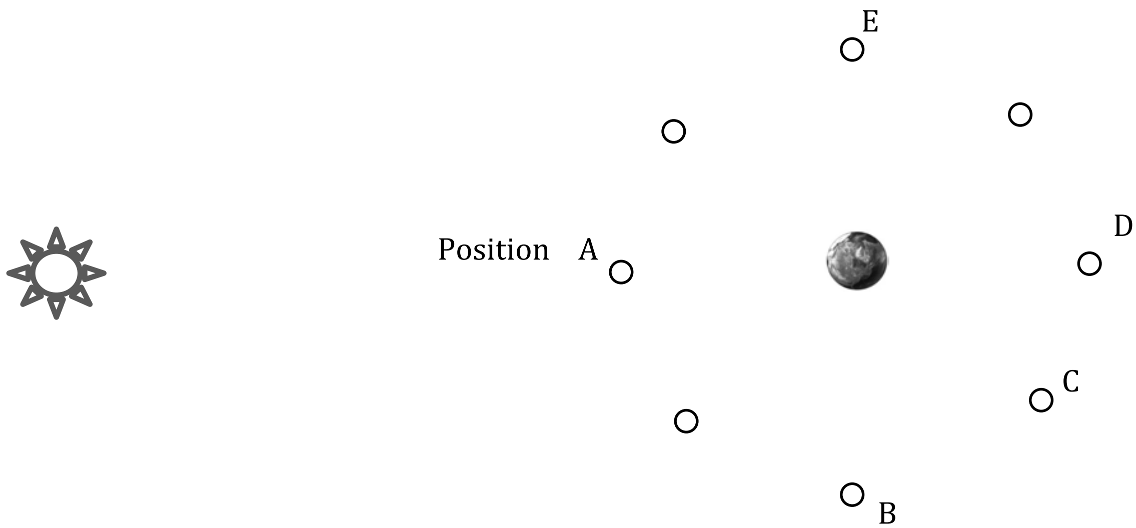
8. How would his measurement have been different if he mistakenly thought the two cities were much farther apart? *Explain*.

The specific positions of Solar System objects in their orbits around the Sun determines where and when they are seen in the sky. Objects located in the same direction as the Sun will be seen in roughly the same direction as the Sun, whereas objects that are observed to be opposite part of the sky are most easily seen at midnight.



1. The Earth-based horizon figure at right shows the position of the Moon as seen high in the southern sky at sunset. Where is it in its orbit as seen from high above the Solar System in the figure below?

Circle one: A B C D E



2. Where would the Moon be if it were visible high in the sky at midnight?

Circle one: A B C D E

3. At what position would the full Moon be if it was rising in the East at sunset?

Circle one: A B C D E

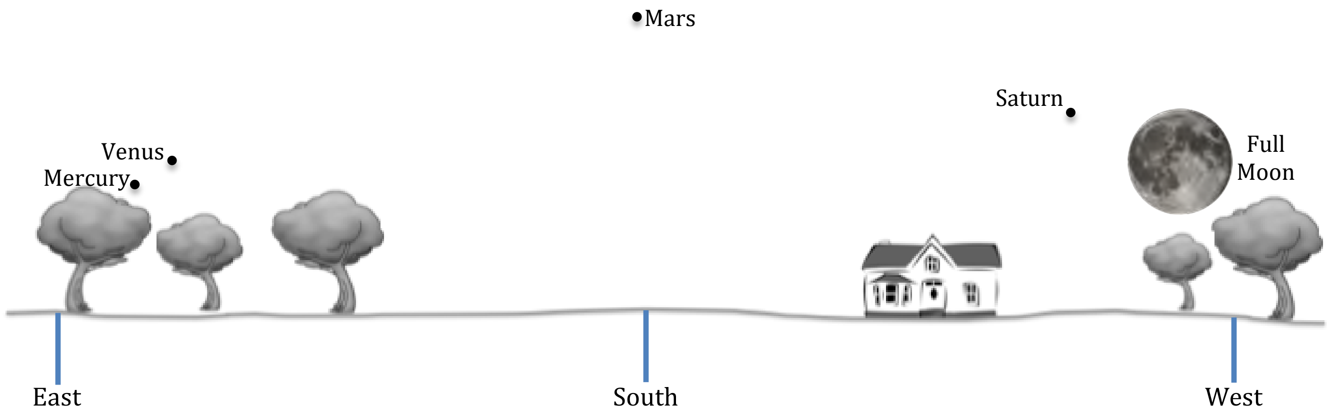
4. Where would the full Moon be if it was setting in the West at sunrise?

Circle one: A B C D E

5. If the planet Jupiter appeared in the sky near the Full Moon, where would it be on the above diagram? *Circle one*:

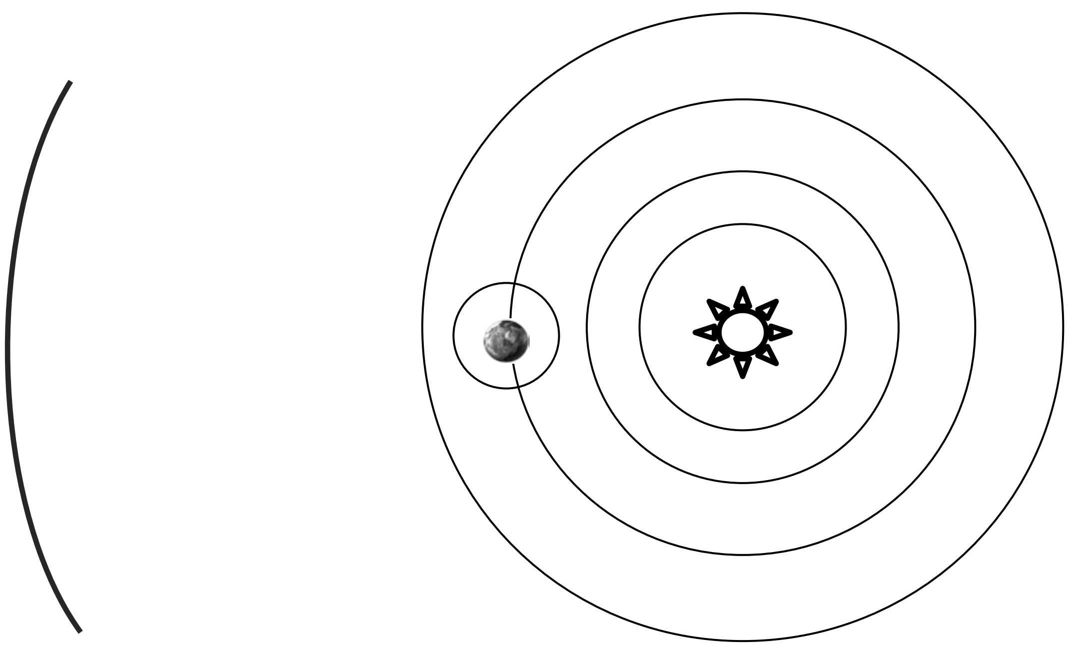
(i) Off to the right hand side, opposite the Sun
(ii) On the top portion of the figure, beyond position E
(iii) On the left hand side, beyond the Sun
(iv) On the lower portion of the figure, beyond position B

Consider this Earth-based horizon view of the sky at sunrise (about 6am) showing Mercury, Venus, Mars, Saturn, and the Full Moon.



6. On the Sun-centered figure below, sketch a stick figure observer at the 6am position.

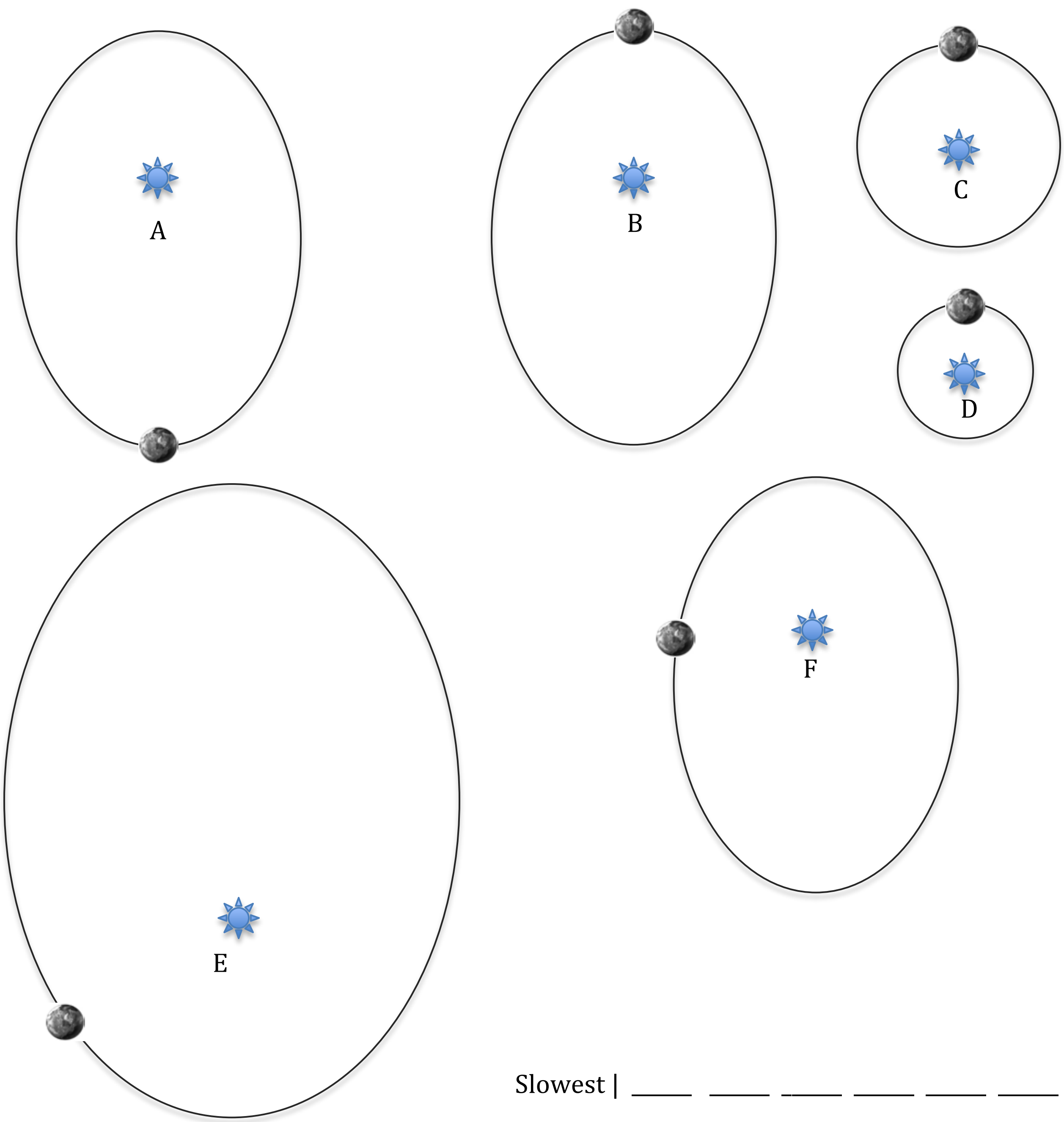
7. Place and label small dots to represent the positions of Solar System objects Mercury, Venus, Earth's Moon, Mars, and Saturn as they orbit the Sun that matches the horizon view above. (*Figure is not to scale*.)



During the Renaissance, many astronomers tried to come up with strategies for accurately predicting the positions of the planets in the sky. After many years, Kepler was able to sum up the motions in the Solar System with three rules.

- Planets orbit the Sun *not* in perfectly circular orbits, but in elliptical orbits.
- Planets orbit fastest when closest to the Sun, and slowest when they are farthest away.
- Planets with orbits closer to the Sun move faster than planets with orbits farther from the Sun.

1. Rank order these illustrations of planet speeds, from slowest to fastest.



Slowest | _____ _____ _____ _____ _____ _____ | Fastest

2. Highlight or darken the part(s) of each planet's orbit, where it is traveling at its fastest.

The planet Jupiter has four large moons. From smallest orbit to largest orbit, they are: Io, Europa, Ganymede, and Calisto, as shown below. Use the rules of planetary motion to answer the following questions. (*Figure not to scale*.)

3. Which moon has the highest orbital speed?

Circle one: Io Europa Ganymede Callisto

4. Which moon takes the longest to orbit once?

Circle one: Io Europa Ganymede Callisto

5. Which moon has the shortest orbital period?

Circle one: Io Europa Ganymede Callisto

6. Which moon is moving slowest, when most distant from Jupiter?

Circle one: Io Europa Ganymede Callisto

7. If Io is the smallest moon, and Ganymede is the largest, which of the four moons moves slowest?

Circle one: Io Europa Ganymede Callisto

Isaac Newton proposed that the GRAVITATIONAL ATTRACTION between two objects is made up of two parts: (i) how much mass the two objects have and (ii) how far apart they are, with the distance between usually being more important because gravitational attraction follows the inverse square distance law.

1. Image two space ships are separated by 10,000 m. If you had a calculator, you could calculate the gravitational attraction between them. Instead, suppose that one ship ejects ½ of its fuel, so that it is holding less fuel. How does the gravitational attraction between them change?

Circle one: it increases   it decreases   it is unchanged

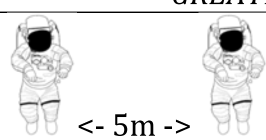
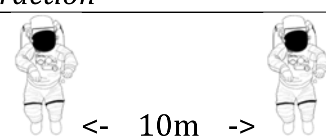
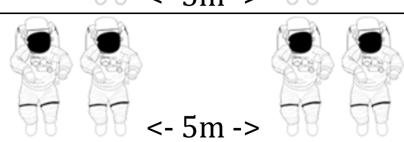
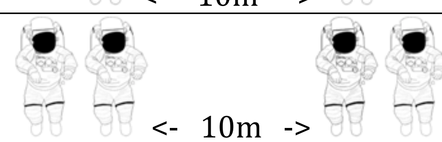
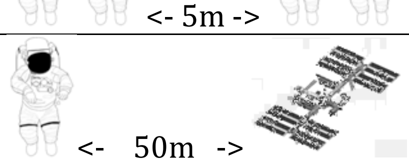
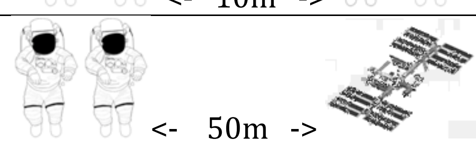
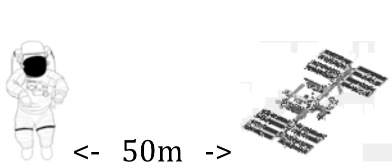
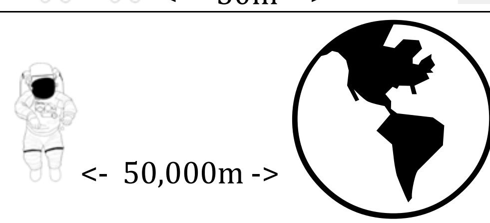
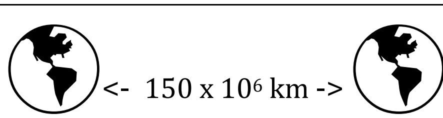
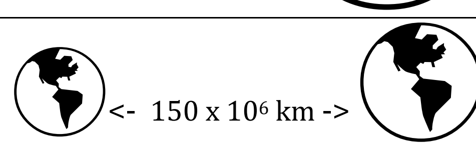
2. Instead of one ship ejecting its fuel, suppose that the distance between them is doubled to 20,000 m. How does the gravitational attraction between them change?

Circle one: it doubles   it becomes ½   it becomes ¼   it becomes $^1/_{16}$

3. Suppose instead that the distance between them is quadrupled to be 40,000 m (becomes four times bigger). How does the gravitational attraction between them change?

Circle one: it doubles   it becomes ½   it becomes ¼   it becomes $^1/_{16}$

Two situations are given in the table rows below. In the middle column below, circle the ARROW pointing toward the scenario where there is GREATER gravitational attraction.

	Circle the arrow pointing to the GREATEST gravitational attraction		
4.	 <- 5m ->	← →	 <- 10m ->
5.	 <- 5m ->	← →	 <- 10m ->
6.	 <- 50m ->	← →	 <- 50m ->
7.	 <- 50m ->	← →	 <- 50,000m ->
8.	 <- 150 x 10^6 km ->	← →	 <- 150 x 10^6 km ->

9. Two astronomers are arguing about the nature of gravity for moving spacecraft.

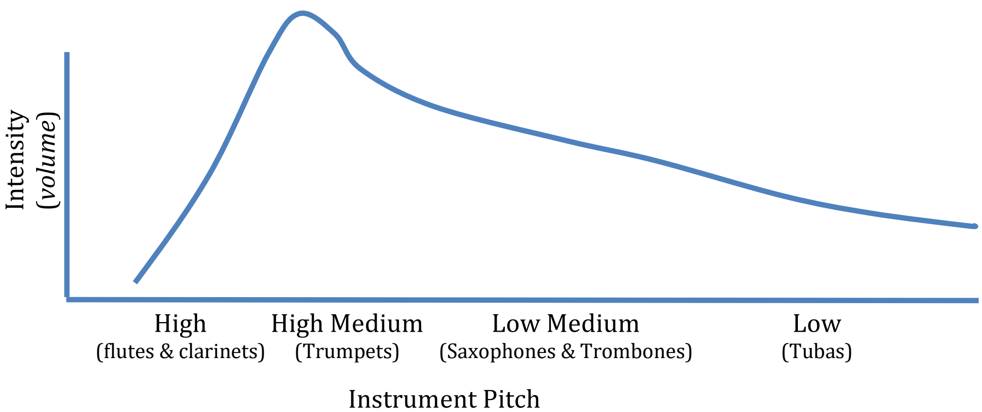
Astronomer Pat: If I've got a spacecraft traveling toward Pluto at 35,000 mph and it runs out of fuel too quickly, it will slowly drift to a stop before it reaches Pluto.

Astronomer Chris: I disagree. A moving spacecraft will maintain its speed without its engines, unless it is acted upon by Pluto's gravitational attraction, then it will start to speed up as it moves closer to Pluto.

With which astronomer do you agree with and why? Explain

Stars, and most glowing objects, emit light at many different wavelengths; however, usually in not in equal amounts. Astronomers often describe the energy output of stars using a graph of intensity versus wavelength. This is similar to how we could describe the music output of a marching band, where some instruments put out more volume than others.

Marching Band Music Output Intensity Graph



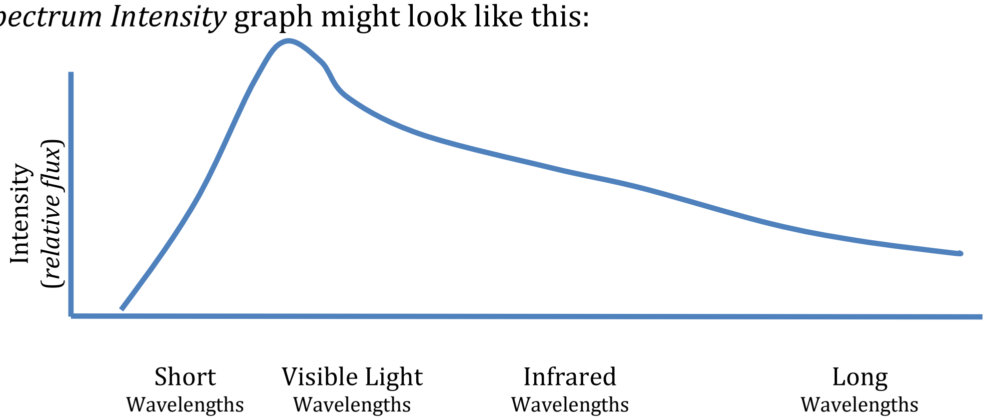
1. Using the information in the *Marching Band Intensity* graph above, which types of instruments are providing most of the band's greatest intensity?

Circle one: Flutes & Clarinets Trumpets Saxophones& Trombones Tubas

2. If you were to consider the total amount of sound emitted of the marching band, not just which instrument is loudest, which of the instrument types are providing most of the sound (area contained by the graph)?

Circle one: Flutes & Clarinets Trumpets Saxophones & Trombones Tubas

Instead, consider the wide spectrum of light waves emitted by glowing stars. One *Starlight Spectrum Intensity* graph might look like this:



3. For this star, which wavelengths of light have the maximum intensity?

Circle one: Short Visible Infrared Long

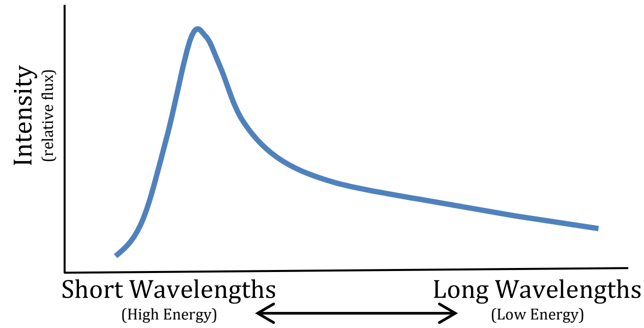
4. For this star, which wavelengths account for most of the star's total energy output?

Circle one: Short Visible Infrared Long

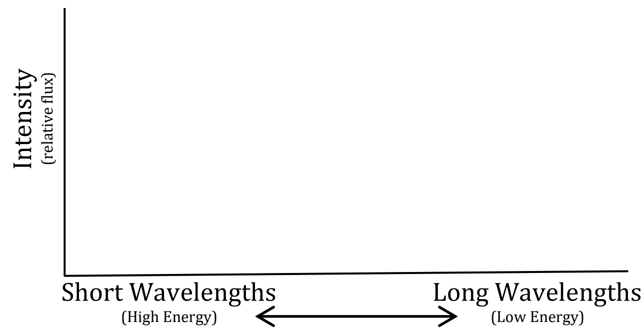
The three most important characteristics of an output spectrum are:

(i) how high is the maximum wavelength peak's intensity
(ii) which wavelength is being most intensely emitted, and
(iii) how much total energy (total area captured under the line) is being emitted

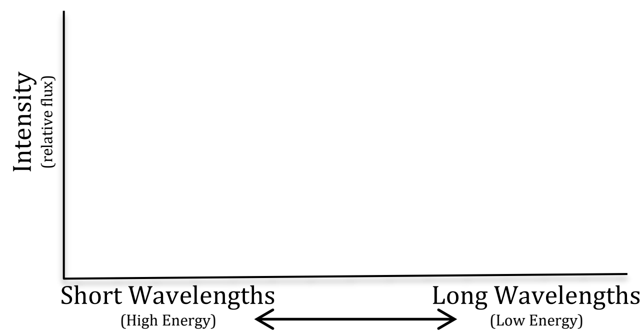
At right is a rough sketch of a star's spectrum of energy emissions, describing the range and intensities of different wavelengths a star might emit (sometimes called a blackbody curve).



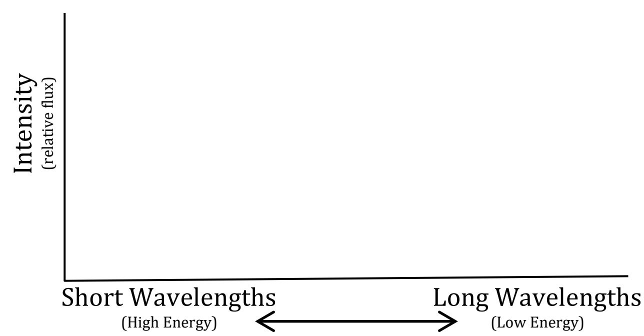
5. If higher temperature stars emit more energy overall, and have an even higher maximum intensity peak occurring at shorter wavelengths, sketch a higher-temperature star's spectrum.



6. If lower temperature stars emit less energy overall, and have a relatively lower maximum intensity peak occurring at longer wavelengths, sketch a lower-temperature star's spectrum.



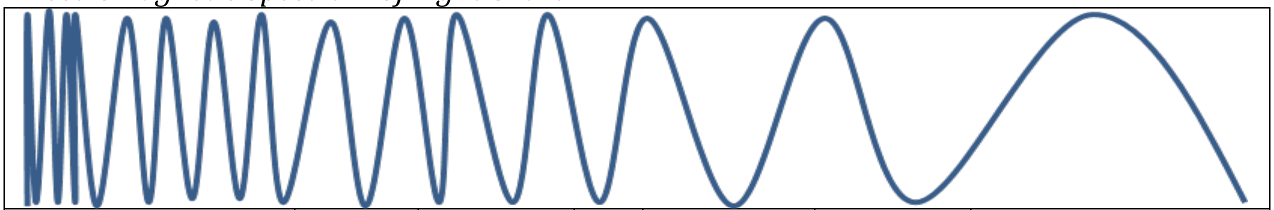
7. Stars that are moving away from us through outer space have spectra that are the same size and shape, but are shifted toward longer wavelengths (called a Doppler red-shift). Sketch a star moving away from us.



Nature of Light 12

All objects in the Universe give off energy in some form of light. Let's first consider the spectrum of different forms of light, by circling the correct relative values in the table below.

Electromagnetic Spectrum of Light Chart



Gamma rays	X-rays	Ultra Violet	Visible	Infrared	Micro-waves	Radio Waves

1.	*Circle one:* Shorter or Longer	⇦ Wavelength ⇨	*Circle one:* Shorter or Longer
2.	Higher or Lower	⇦ Frequency ⇨	Higher or Lower
3.	Higher or Lower	⇦ Energy ⇨	Higher or Lower
4.	Bigger or Smaller	⇦ Changes in Electron State ⇨	Bigger or Smaller

> *Your brain might hiccup when talking about light because it seems like there are two different kinds of energy being emitted: rays of photon particles and waves of light. They are both the same thing, even though astronomers use different terms to talk about different parts of the spectrum. They are all forms of electromagnetic radiation. Don't let the words cause you confusion.*

One mental cartoon about how light is emitted from an atom has to do with electrons releasing energy as light when they naturally move from higher-than normal outer positions around the center to closer, lower energy positions.

5. Compared to a small change in an electron's state, a large change results in emission at:

(*Circle one*) higher energy lower energy no difference

6. Compared to a small change in an electron's state, a large change results in emission at:

(*Circle one*) longer wavelength shorter wavelength no difference

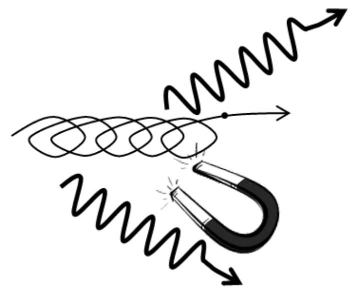
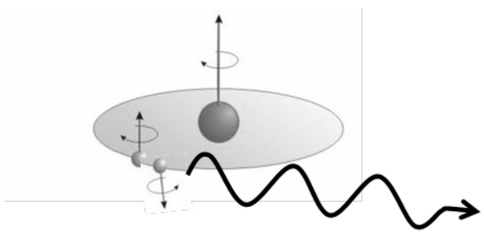
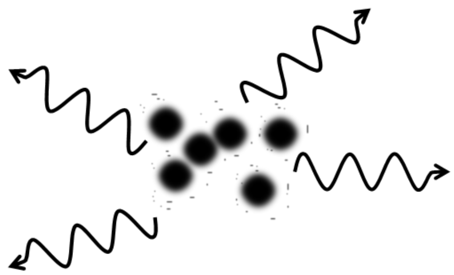
7. Compared to a small change in an electron's state, a large change results in emission at:

(*Circle one*) higher frequency lower frequency no difference

8. Compared to a small change in an electron's state, a large change results in emission at:

(*Circle one*) higher speeds lower speeds no difference

Below are illustrations showing other ways that light can be generated besides electrons changing their distance from an atom's center. In almost every case, light is emitted when an electron changes its path.

	
(A) Light emitted when an electron passes by a positively charged atom	(B) Light emitted when an electron spirals through a magnetic field
	
(C) Light emitted when an electron in an atom flips upside down	(D) Light emitted when atoms with electrons vibrate

10. Use the illustrated wavelength shown, or your best guess about how much an electron is changing its position, to rank order these four light producing processes (A, B, C and D).

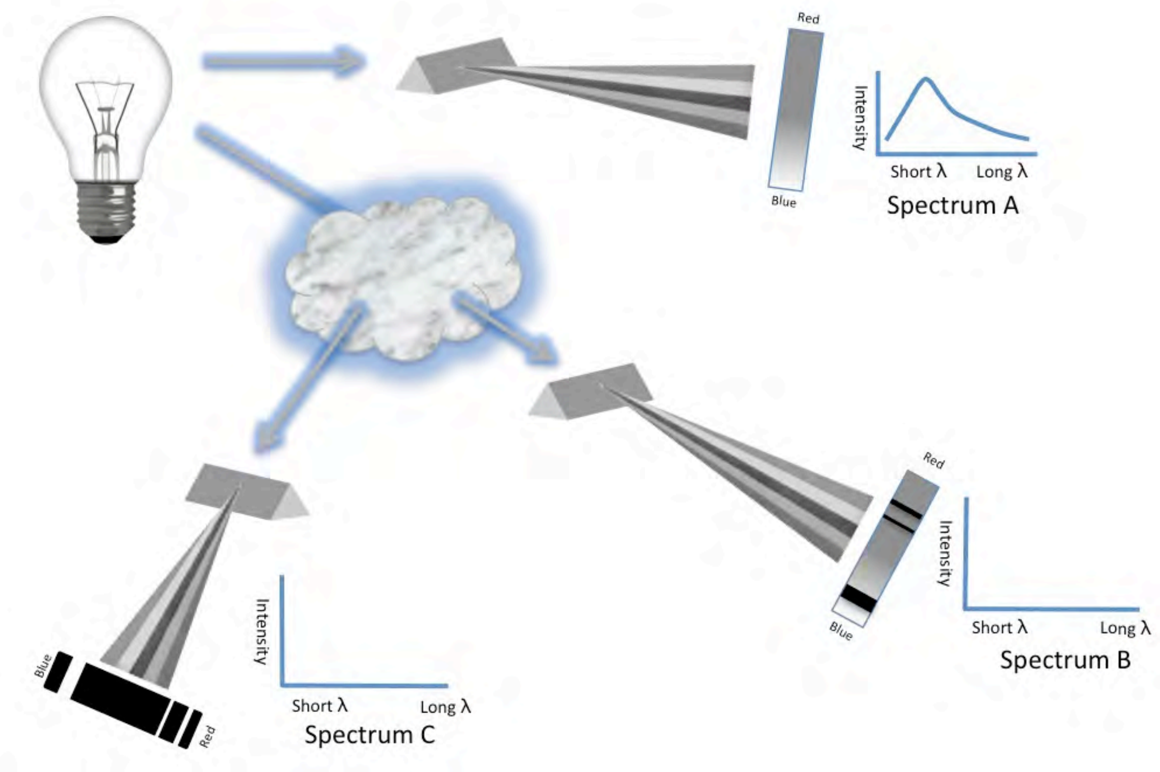
Rank Order:	___	___	___	___
	Highest ⇦ Energy of Light Given Off ⇨ *Lowest*			

Match the illustrations with an astronomical event in the table below.

		Energy	Process
example	*Supernova explosion of star*	*Very High*	*A*
12.	Warm dust heated by young stars	Medium-Low	
13.	Cold gas & dust between stars	Low	
14.	Super heated gas pulled rapidly toward a black hole	Medium-High	

Kirchoff's Rules 13

Because stars are so far away, it is unlikely that we will ever visit them. Instead, astronomers must study the detailed characteristics of light to uncover the way the Universe works. The best way to study the light we receive is to spread it apart into its component spectrum of colors using a prism or spectroscope. As we study the spectrum of an object we have to think about the environment that the light has passed through.



1. With a full, colorful rainbow, what kind of spectrum is graph "A" ?
   Circle one: continuous emission absorption

2. A rainbow with certain characteristic colors removed is what kind of spectrum?
   Circle one: continuous emission absorption

3. A spectrum having just a few characteristic colored lines is what kind?
   Circle one: continuous emission absorption

4. Sketch the spectral curve for the emission spectrum. *For this imaginary situation, the thickest line is slightly to the left of what is normally the peak, maximum intensity.*

5. On the previous page, sketch the spectral curve for the absorption spectrum. *For this imaginary situation, the thickest line is slightly to the left of what is normally the peak, maximum intensity.*

Use arrows in the space below to match the following Kirchoff's Rules for Spectroscopy with their name:

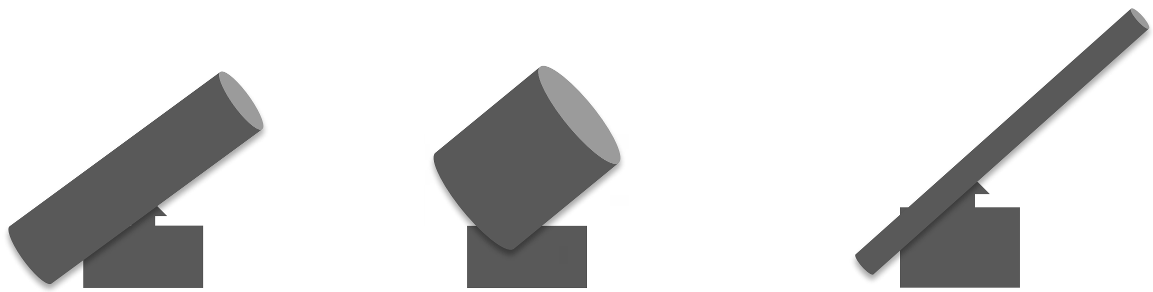
6. Continuous spectrum	A: Spectrum resulting from viewing a hot, dense glowing object through a cloud of intervening gas or dust
7. Emission spectrum	B: Spectrum resulting from viewing light received from a glowing cloud of gas or dust
8. Absorption spectrum	C: Spectrum resulting from viewing light received from a hot, dense, glowing object

9. When observing the Sun's spectrum from the nearly atmosphere-free Moon's surface, we observe an absorption spectrum with many lines. Propose why certain wavelengths of light might be missing from the spectrum.

10. When observing the Sun's spectrum from the Earth's surface, we observe an absorption spectrum with even many more lines than were observed from the Moon. Propose why there are even more missing wavelengths when the Sun's spectrum is observed from Earth's surface.

It is difficult to image doing astronomy without a telescope. The three main tasks of a telescope are to: (i) gather and focus light from distant objects; (ii) see fine details; and (iii) magnify nearby objects

LIGHT GATHERING POWER: The ability of a telescope to gather and focus light from distant objects is closely related to its diameter.



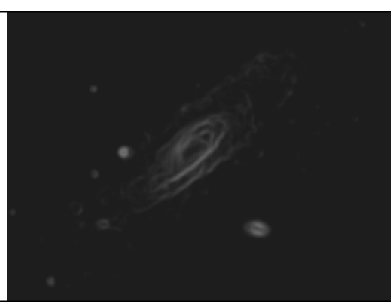
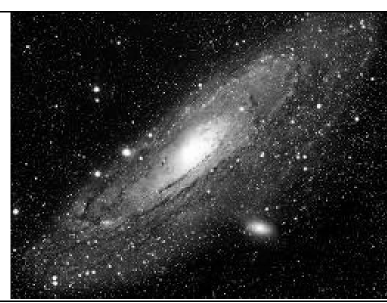
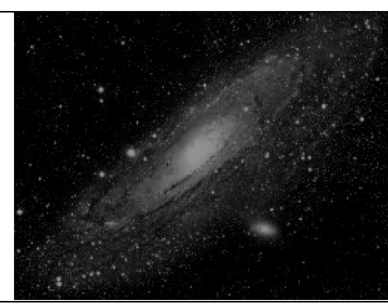
Telescope A Telescope B Telescope C

1. Rank order these telescopes (A, B, and C) from greatest to lowest light gathering power.

Greatest Light Gathering Power	_____ _____ _____	Lowest Light Gathering Power

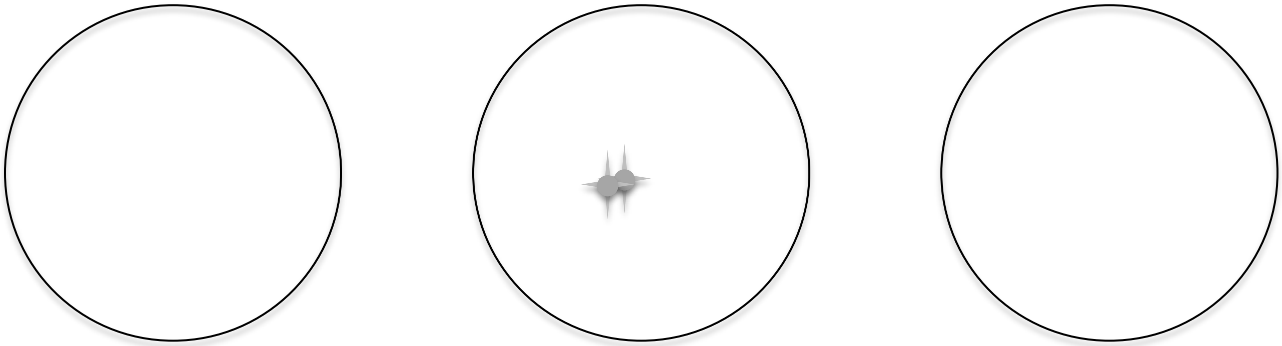
2. A telescope's light gathering power is largely based on its total collecting area, which can be calculated with the simple formula, πr^2, where "r" is the radius. How much more light gathering power does an 8-m telescope compared to a 2-m telescope?

SEEING FINE DETAIL: Better telescopes are able to resolve fine detail.

		
Picture from Tiger Telescope	Picture from Canary Telescope	Picture from Gomez Telescope

3. These three pictures are of the same galaxy of stars, taken by three different telescopes. Circle the one with the greatest ability to resolve fine detail.

4. Below is a sketch of how a binary star system looks through a telescope—where two stars are found very close together. On the left, sketch what a lower resolution would look like, and on the right, a higher resolution.



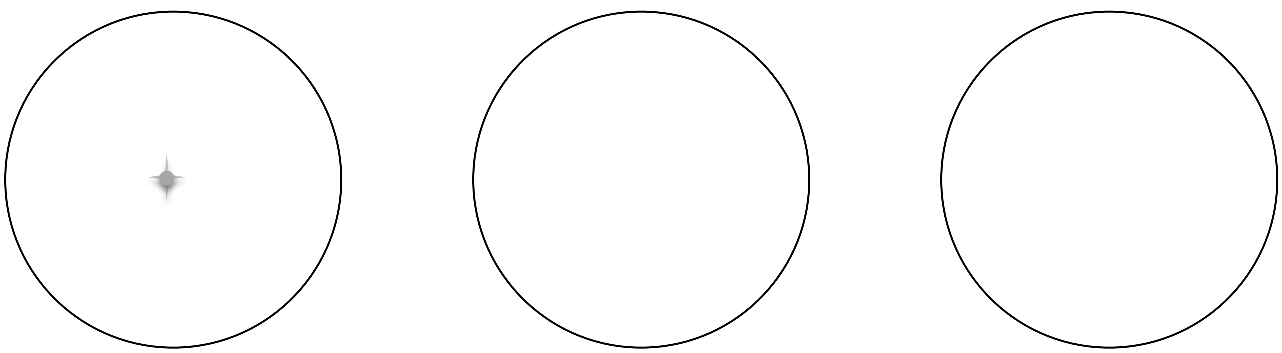
Picture from Green Telescope (*low resolution*)

Picture from Red Telescope (*medium resolution*)

Picture from Blue Telescope (*high resolution*)

MAGNIFICATION: The least valuable part of a telescope is its ability to magnify. This is because even the largest stars are so far away, that most stars will still look like the same tiny pinpoints of light, regardless of the telescope.

5. Here is a sketch of a star as seen in a low magnification telescope. In the remaining two circles, first sketch what a medium magnification would look like, and then on the right, a higher magnification would look like.



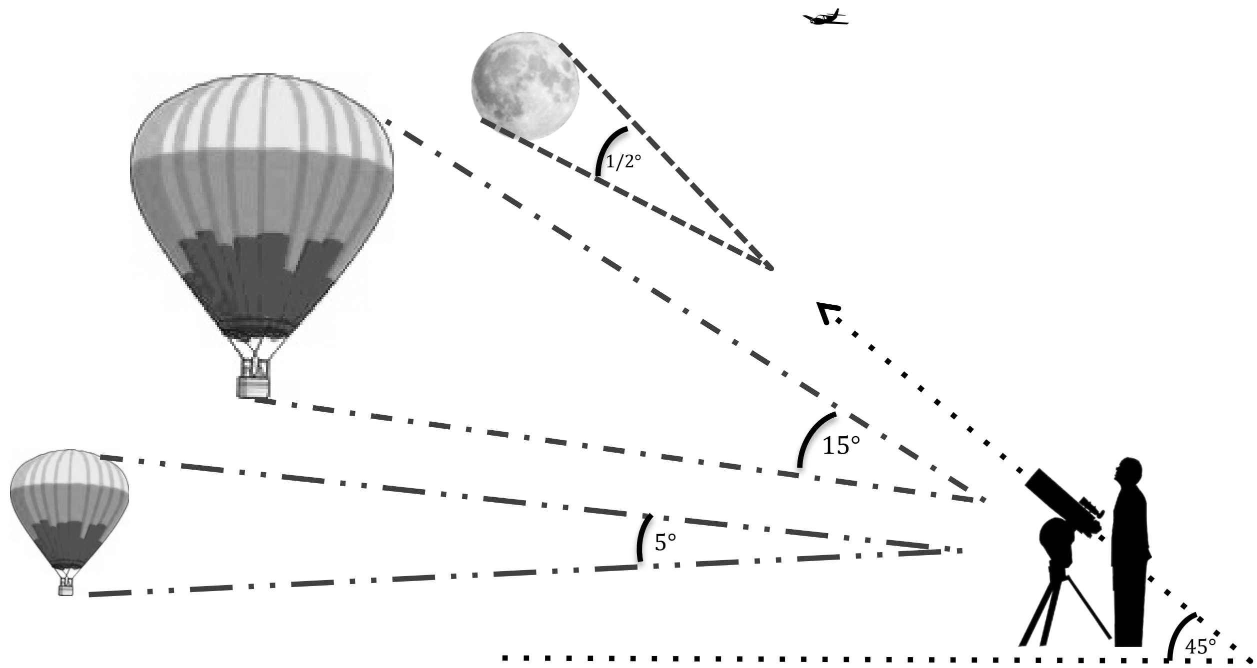
Sketch from a low magnification telescope

Sketch from a medium magnification telescope

Sketch from a high magnification telescope

> *Your brain normally wants to think that bigger—more magnification—must be better. In many cases that is true. However, in astronomy, we're usually looking at very distant objects whose size is too small to expand. Worse, by using magnification we can actually spread out the little light that is being captured, making the star harder to see.*

When talking about how big objects appear in the sky, it doesn't make sense to say that the Moon is 2-in across or 6-m above the horizon. Instead, astronomers use angular sizes, measuring in degrees. Something that takes up the whole sky would be 180°, and something that takes up half the sky is 90°.



What is the apparent angular size or height for each of the items shown in the Figure above?

SMALL SIZES: In astronomy, many sizes and distances are smaller, and can be fractions of a degree.

In using angular measures, we often subdivide a degree of arc into 60 minutes, and subdivide a minute of arc into 60 seconds of arc.

1. Altitude of the Full Moon above horizon?

Circle one: ½° 5° 15° 45°

2. Apparent angular size of Full Moon?

Circle one: ½° 5° 15° 45°

3. Apparent angular size of nearby 5-story tall, hot air balloon?

Circle one: ½° 5° 15° 45°

4. Apparent angular size of 5-story tall, hot air balloon off in the distance?

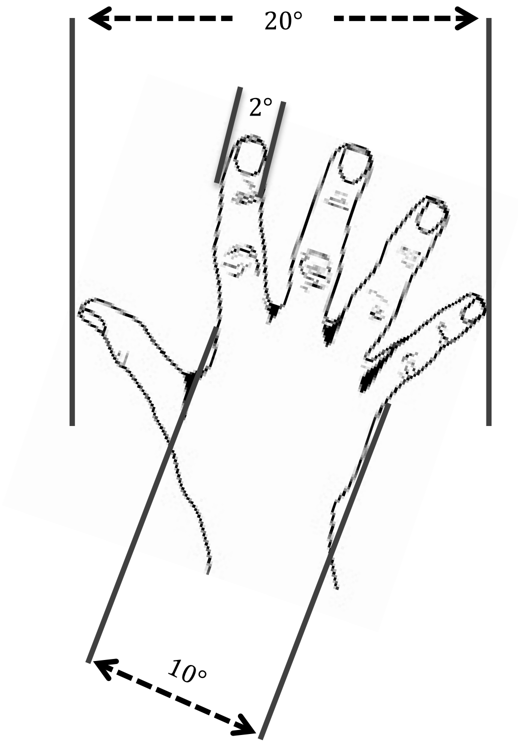
Circle one: ½° 5° 15° 45°

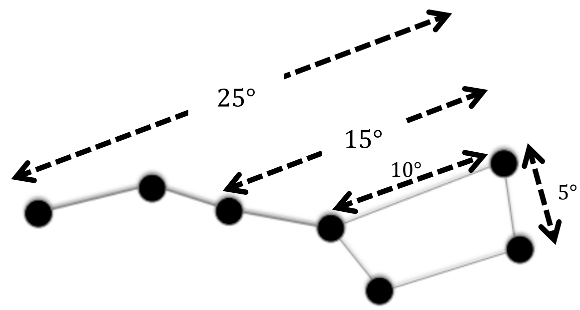
5. If the Full Moon extends about ½ of arc, how many minutes of arc is this?

Circle one: 30' 50' 3600"

6. The 20-m (60-ft) long airplane flying in the distance appears to be about ½ the size of the much larger 3,500 km (2,000 mile) diameter Moon. What is this airplane's apparent angular size?

Stretching out your arm as far as it will go, you can make angular size estimates using your hand as a sort of angular ruler. (*You can also do this with the Big Dipper, as shown at right.*)





7. What is the angular size of a cell phone at arm's length? (*measure the longest side*)

8. How big does that that same cell phone appear from about 5 feet away?

9. How big does the cell phone appear 10 feet away?

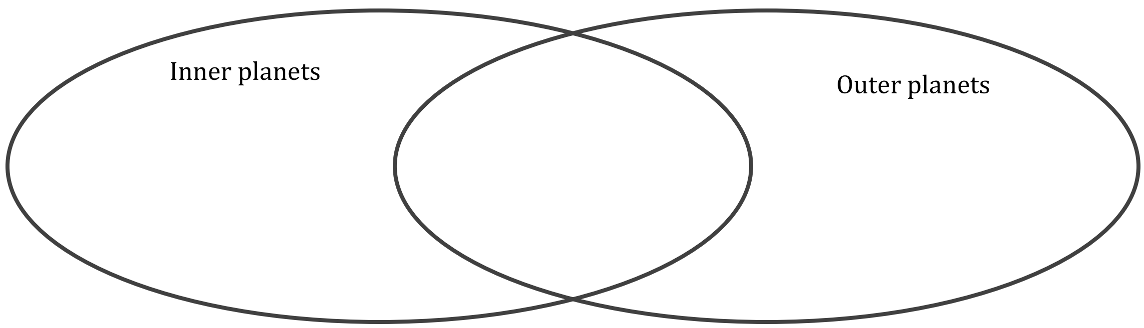
10. What is the angular size of the nearest window or door?

Planetary Science

Our Solar System of planets stretches more than four billion miles from the Sun. Let's see if we can build a better mental model on the distribution of the objects orbiting our Sun.

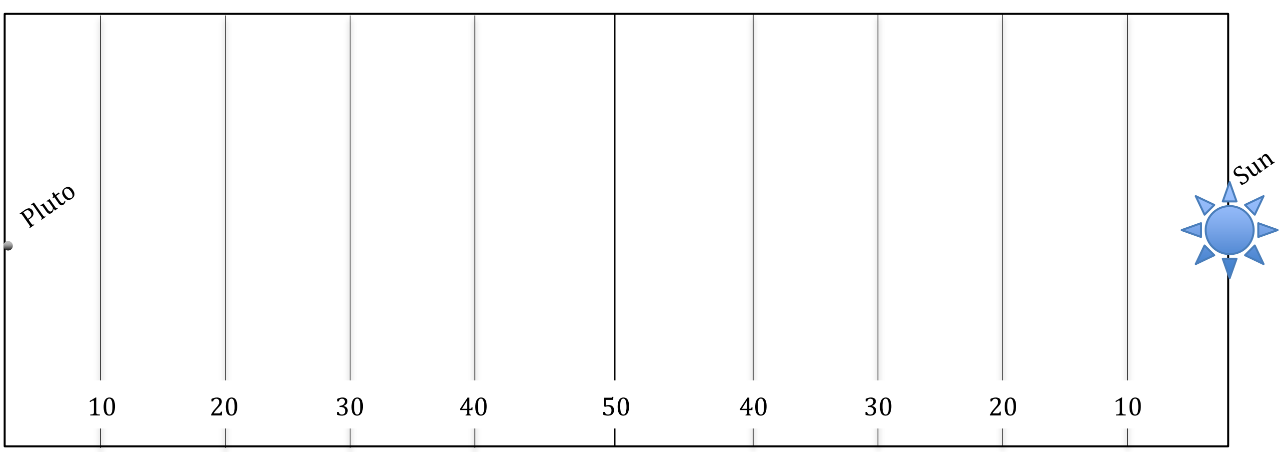
1. List the eight planets, in order of increasing distance from the Sun.

2. Write the names of each of the eight planets in the appropriate place in the Venn Diagram.



3. Imagine making an accurately scaled model of the Solar System on a 100-yard long football field, with the Sun on one end, and Pluto on the other.

Without using a book, or the Internet, or any resource, place and label a dot for your best guess orbital distance for each of the eights planets orbiting from the Sun.



Let's now consider the known average distances of our Solar System's planets.

A convenient unit to use for planetary distances is the *astronomical unit*, or AU, which is the average distance between Earth and the Sun.

Mercury	Venus	Earth	Mars	Jupiter	Saturn	Uranus	Neptune	Pluto *
40% AU	70% AU	1 AU	1 ½ AU	5 AU	10 AU	20 AU	30 AU	40 AU

*Pluto is a dwarf planet

4. Using the above table, notice that Pluto is about 40 AU from the Sun. Which planet is about half way between the Sun and Pluto? *Label it on the football field figure below.*

5. Which planet is half way between the Sun and the mid-point planet? *Label it on the football field figure below.*

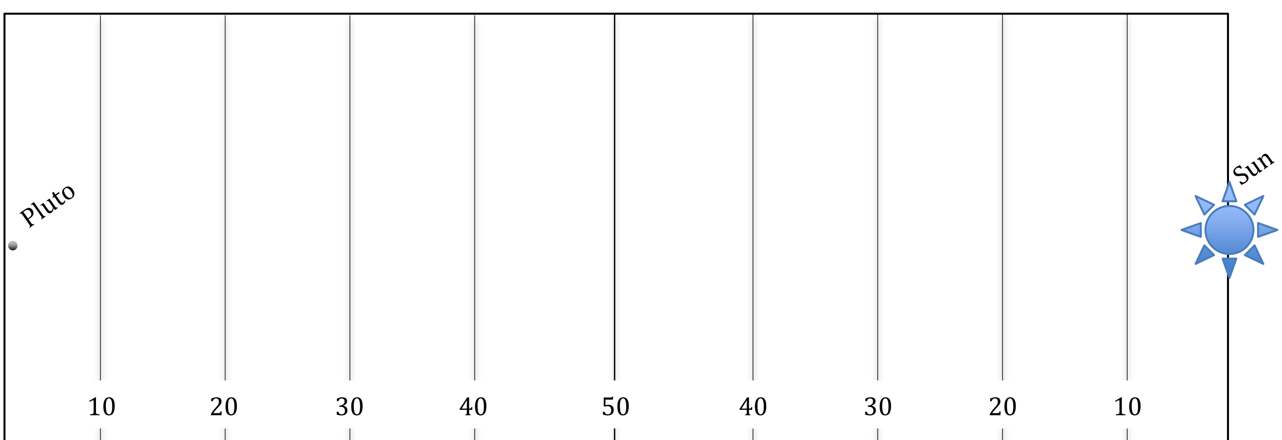
6. Which planet is about half way between the Sun and the planet identified in the previous question? *Label it on the football field figure below.*

7. Earth is $^{1}/_{5}$ the distance between the Sun and Jupiter (or $^{1}/_{40}$ the distance between the Sun and Pluto). *Label Earth on the football field figure below.*

8. Using the information in the table above, insert and label the remaining planets.

9. Should Mars be considered an inner planet, an outer planet, or neither/both?

11. How is your new sketch of the Solar System different on this page than on the previous page?



10. If a radio signal can get to Saturn in 1 hour and 11 minutes, about how long would one take to get to Uranus? *Explain how you came up with your answer.*

There are thousands of other planetary systems with planets orbiting stars other than our Sun. Because of the consistent way planetary systems are formed, there seem to be some characteristics common to many—but not all—planetary systems.

1. In the Table below, use the given list to write object names that are examples of the planetary system object categories. *Answers can be used more than once.*

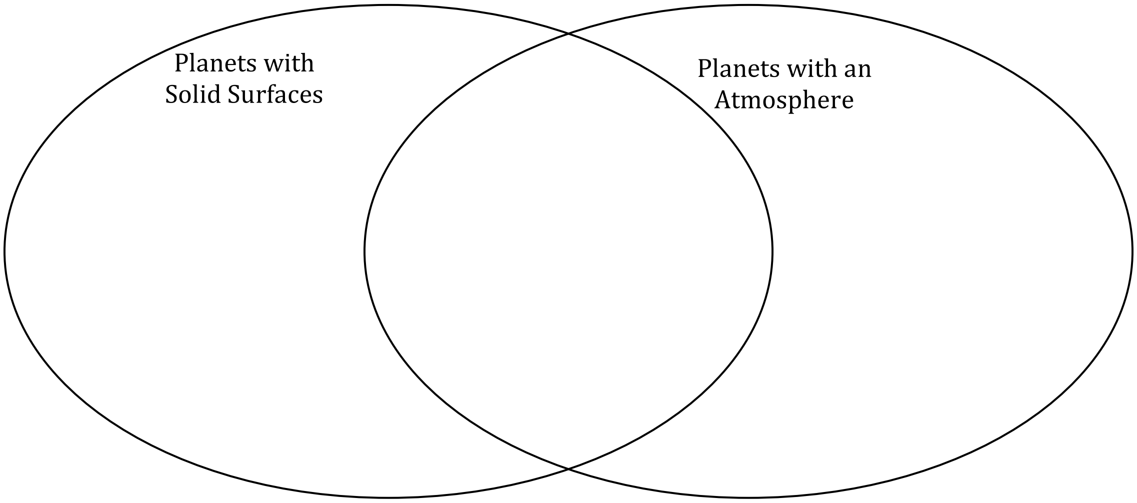
Stars			
1.			
Planets			
1.	2.	3.	4.
5.	6.	7.	8.
Dwarf Planets			
1.	2.	3.	
Moons			
1.	2.	3.	
Asteroids			
1.	2.	3.	
Kuiper Belt Objects			
1.	2.	3.	
Comets			
1.	2.	3.	

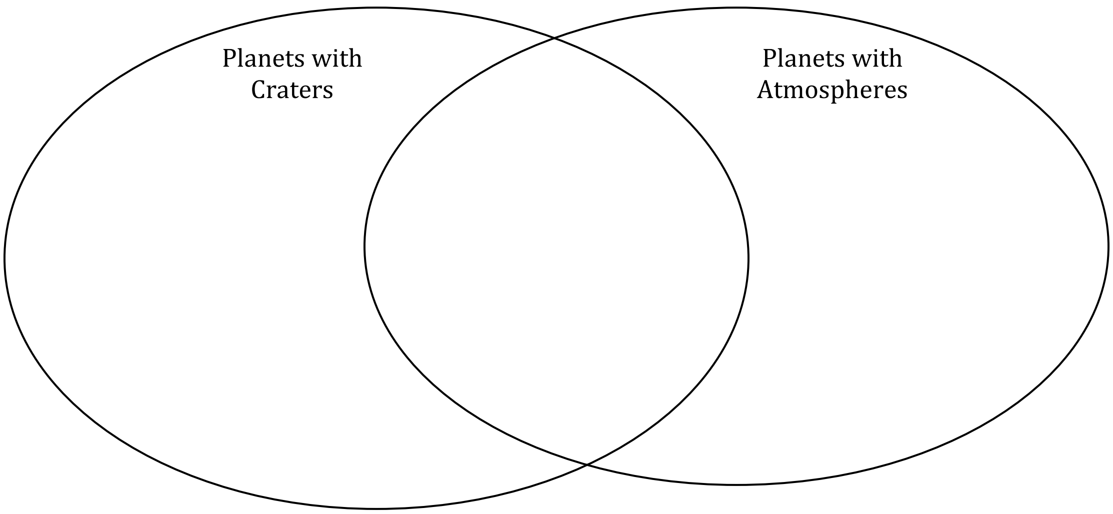
This is not an exhaustive list; other objects exist and some names should be listed in more than one category.

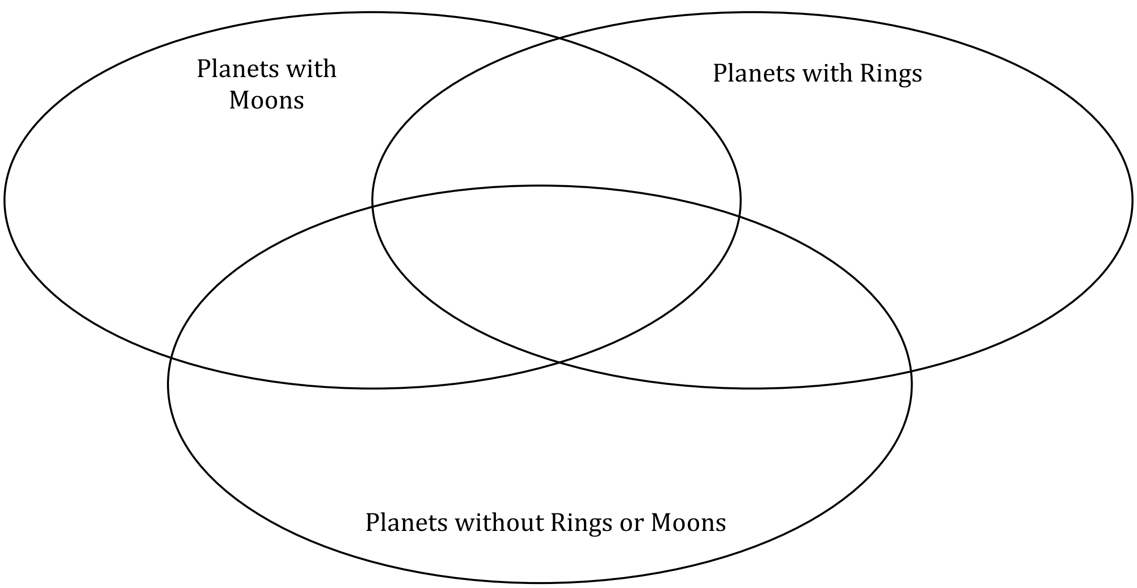
List of names to include in Table above:

☐ Mercury	☐ Uranus	☐ Saturn	☐ Neptune
☐ Shoemaker Levy-9	☐ Sun	☐ Venus	☐ Halley
☐ Jupiter	☐ Eris	☐ Ceres	☐ Haumea
☐ Makemake	☐ Earth	☐ Juno	☐ Moon
☐ Titan	☐ Swift-Tuttle	☐ Pluto	☐ Mars
☐ Vesta	☐ Tritan	☐ Sedna	

2. On the next page, complete each of the three sets of Venn Diagrams describing the eight planets of our Solar System by writing planets' names inside the correct circles.


Planets with Solid Surfaces
Planets with an Atmosphere

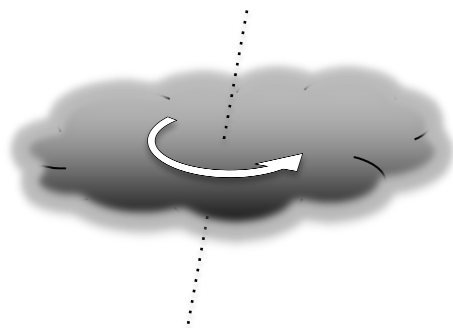

Planets with Craters
Planets with Atmospheres


Planets with Moons
Planets with Rings
Planets without Rings or Moons

Formation of Solar System 18

Our Solar System formed in much the same way as all we think most planetary systems form—from the materials remaining from the formation of stars.

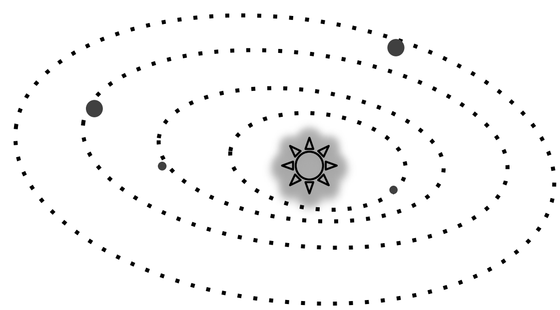
1. Drawing arrows, MATCH each description with its corresponding sketch.



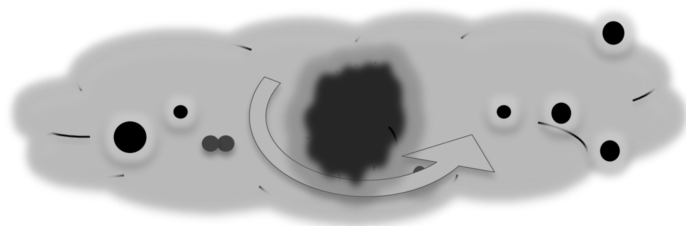
CLOUD PHASE: Giant clouds of dust and gas—often light-years across in size—exist in the interstellar space between stars.

SPINNING & COLLAPSE: Perhaps because of a nearby supernova shock wave or because of gravitational attraction, parts of a giant cloud will begin to collapse due to gravitational or electrical attraction between particles of the cloud. When it shrinks, it begins to spin and flatten.

CLUMPING OF PLANETOIDS: Many small clumps begin to form through repeated collisions where the materials stick together. At the same time, to early beginnings of a star occur at the center.



CLEARING OUT THE LEFT-OVERS: As the central star becomes brighter and emits a stable wind of energy, the smallest materials are blown out of the system, and the few remaining orbiting objects become the planets, dwarf planets, asteroids, and frozen comets we observe today.



Figures not to scale

Part of astronomy is figuring out how long things have been around. You probably know how many years you've been alive, and you might know that you can determine the age of trees by counting the number of growth rings they have. But, how do we know the age of really ancient things, like rocks, or even the Earth itself?

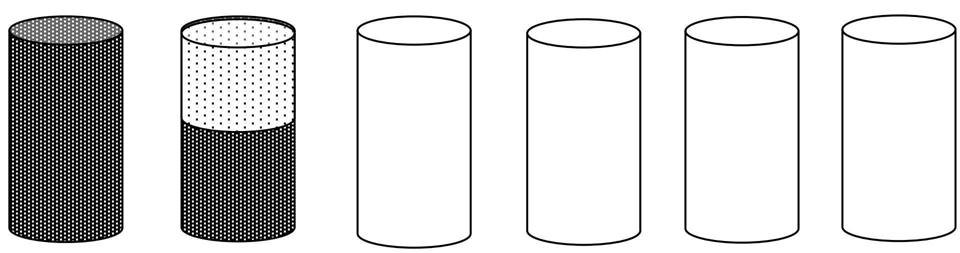
We can determine the age of rocks—whether they are from Earth, the Moon, or some other Solar System object—using a strategy known as RADIOACTIVE DATING. Radioactive dating is based on the idea that:

Certain radioactive elements change into different elements over time at a very specific rate. We can use the ratio of the two elements to determine how old the object is.

1. Radioactive potassium (^{40}K) turns into argon (^{40}Ar) when it decays. Imagine a rock is formed with 64 gazillion ^{40}K atoms and no ^{40}Ar atoms. Use the fact that one-half of all 40K atoms turn into 40Ar atoms every 1 ¼ billion years to complete the table below.

	0 years old	1 ¼ billion years old	2 ½ billion years old	3 ¾ billion years old	5 billion years old	6 ¼ billion years old
Number of ^{40}K Potassium atoms	64 gazillion	32 gazillion	16 gazillion	8 gazillion	4 gazillion	2 gazillion
Number of ^{40}Ar Argon atoms	0 gazillion	gazillion	gazillion	gazillion	gazillion	gazillion

2. Imagine these radioactive atoms could be captured in a glass tube. Sketch the relative amounts of ^{40}K and ^{40}Ar for containers with 2 ½ billion, 3 $^{3}/_{4}$, 5, and 6 ¼ year old samples.



0 years old	1 ¼ billion years old	2 ½ billion years old	3 ¾ billion years old	5 billion years old	6 ¼ billion years old

(*Note: Figures might imply this only happens at one end of the sample; but the conversion happens randomly throughout)*

3. If a rock has 12 gazillion ^{40}K and 52 ^{40}Ar atoms, about how many years old is it?

Circle one: 3 billion 4 ¼ billion 5 $^{2}/_{3}$ billion 12 billion

4. Astronomers carefully analyzed the lunar rocks brought back from the Moon by Apollo astronauts. One of the things they discovered is the Moon rocks have both ^{235}U Uranium atoms and ^{207}Pb Lead atoms. Radioactive ^{235}U atoms have a 700 million year *half life*—it takes about 700 million years for 50% of ^{235}U atoms to become ^{207}Pb atoms.

How old is a rock with the same number of ^{235}U and ^{207}Pb atoms if it started out with no Lead atoms inside?

5. Two astronomers are arguing about the atoms found in an initially Lead-free rock that is about 1.4 billion years old.

> *Astronomer Pat*: ^{235}U has a half-life of 700 million years, so after 1,400 million years, it would have twice as many Lead atoms as Uranium atoms.
>
> *Astronomer Chris*: I disagree. The rock would be 50:50 after its first half-life, but then 75:25 after a second half-life, making 3 Lead atoms for each Uranium atom.

With which astronomer do you agree with and why? *Explain*.

Earth's surface is dynamic. In certain parts of the world, earthquakes shake the ground every day. In other places, volcanoes eject ash into the air, and liquid rock across the ground. Mountains change too—some once tall mountains get smaller every year as wind and water constantly pick off little pieces whereas other mountains get taller every year, being pushed up by the surrounding land or constructed from upwelling magma. Some oceans get wider, while others get smaller. All of this is driven by the mechanisms of plate tectonics.

For the following questions, use the Figure at the bottom of the page.

1. Which crust is thin?

Circle one: denser, ocean crust less-dense, continental crust

2. Use your pencil (*or lightly use ink*) to shade the dense oceanic crust.

3. When ocean crust and continental crust collide, which gets pushed deeper into Earth's hot interior?

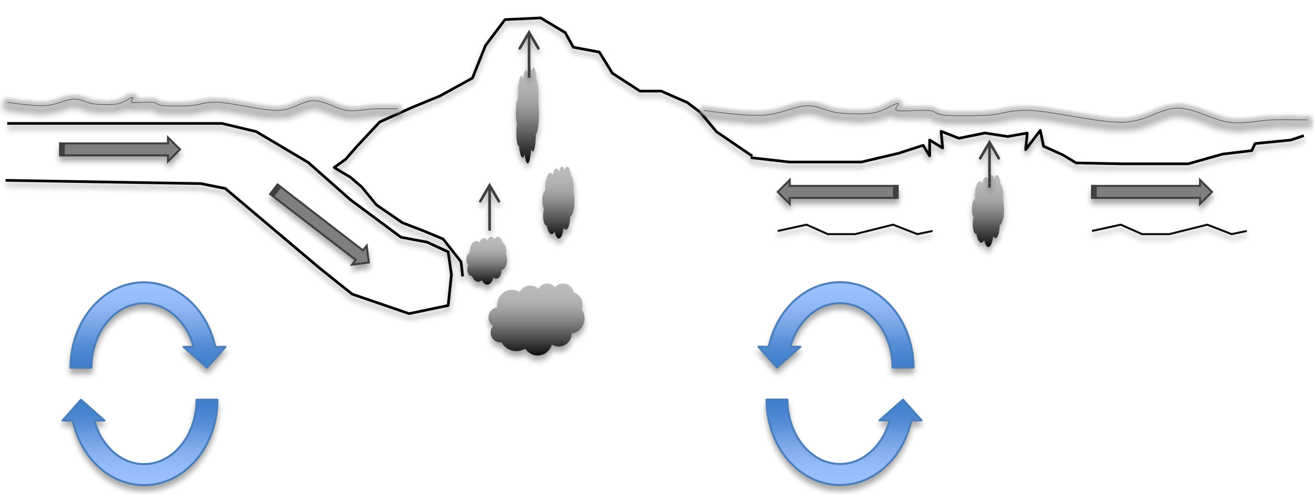
Circle one: denser, ocean crust less-dense, continental crust

4. What are plates doing at a convergent plate boundary?

Circle one: colliding moving apart

5. Label the convergent plate boundry and the divergent plate boundry.

6. Label the deep ocean trench, the volcano, and the underwater mountain ridge.



Many people think that places where Earth is spreading apart—like the center of the Atlantic Ocean—should be places where there would be a deep gap. As it turns out, when Earth's plates spread apart, magma moves upward into the space creating an underwater mountain range, not a deep cavern.

About 300 million years ago, the largest landmass on Earth was a supercontinent we call Pangea. The surrounding ocean is called Panthalassa. (Because Earth is 4 ½ billion years old, there have been many, many earlier continents and oceans.)

300 million years ago	200 million years ago	100 million years ago

8. Dinosaurs became extinct about 65 million years ago. Which panel above most closely resembles what Earth would have looked like then?

Circle one: 300 million 200 million 100 million

9. The oldest homosapien (modern human) fossils are about 200,000 years old. Which panel above resembles what Earth would have looked like then?

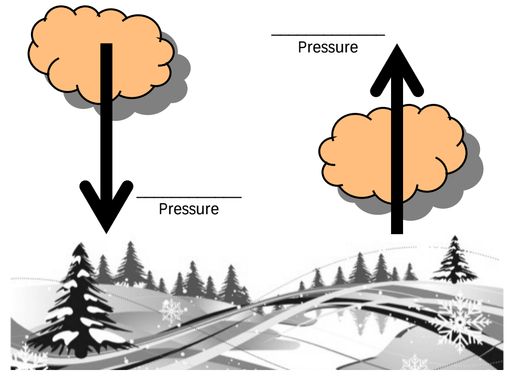
Circle one: 300 million 200 million 100 million

10. The maximum extent of the most recent ice age occurred about 22,000 years ago. Which panel above resembles what Earth would have looked like then?

Circle one: 300 million 200 million 100 million

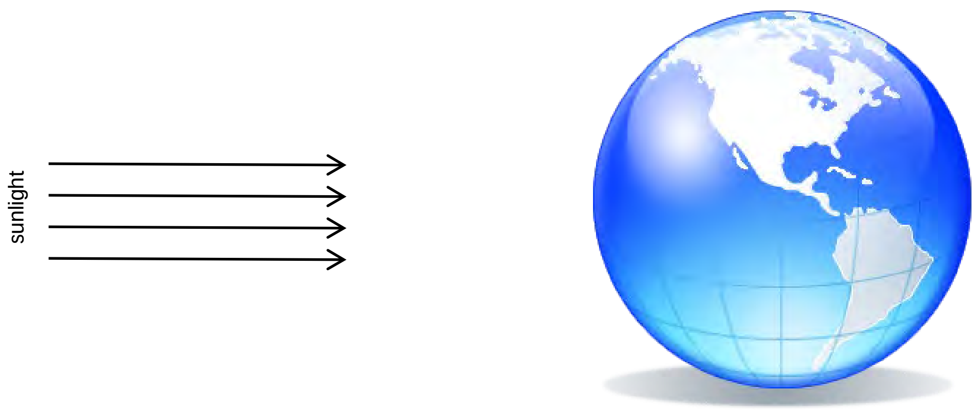
Earth is surrounded by a relatively thin layer of air that presses down on the surface because of Earth's gravitational attraction. Wind is the rapid movement of air from one place to another and is caused by differences in how the Sun heats our spinning Earth.

We often think about wind as something that blows across the surface of the Earth's lands and oceans, but air can also move up and down.



1. When air is moving up and pressing less on Earth's surface, we call it "low pressure." Alternatively, when air is moving downward and pressing more on Earth's surface, we call it "high pressure." *On the figure above, label which is high pressure and which is low pressure by filling in the blanks.*

2. Sunlight most directly heats Earth at the equator. *On the figure below, sketch in a dark line indicating Earth's equator.*



3. At the equator, the heated air expands and rises far above the surface. The air splits and moves about $^{1}/_{3}$ of the way toward each of the poles. *On both the right and left sides, draw curved arrows showing how air moves up and away from the equator to about 30° north and 30° south latitude.*

4. What type of pressure does Earth's surface experience at the equator?

Circle one: High Low

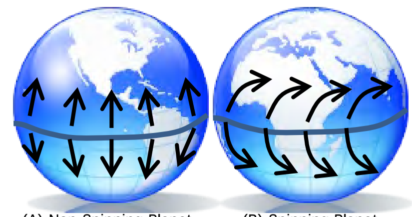
5. Once the air gets to about 30° latitude, it cools and contracts and moves toward the ground. What type of pressure does Earth's surface experience at 30°?

Circle one: High Low

6. When the air reaches the surface again, it moves back to the equator thus completing a circular loop. *Add these circular cells to your sketch using arrows.*

7. The falling air at 30° latitude causes a similar circular cell to form between 30° and 60°, but in the opposite direction. *Add these mid-latitude cells to your sketch.*

If Earth did not spin on its axis, the moving cells of air would look like (A) in the figure at right. However, Earth spins on its axis, which has the odd effect of causing the air currents to bend, or curve, to the right in the northern hemisphere, and the left in the southern hemisphere, as shown in (B).



(A) Non-Spinning Planet (B) Spinning Planet
Upper Level (non-surface) Winds

8. Two astronomers are drawing sketches about the direction of winds across Earth's surface.

	
Astronomer Pat	Astronomer Chris

With which of these two astronomers do you agree and why? *Explain.*

9. Sailing ships often have difficult crossing the equator because a constant low pressure system exists there. From which direction does the wind generally blow near the equator?

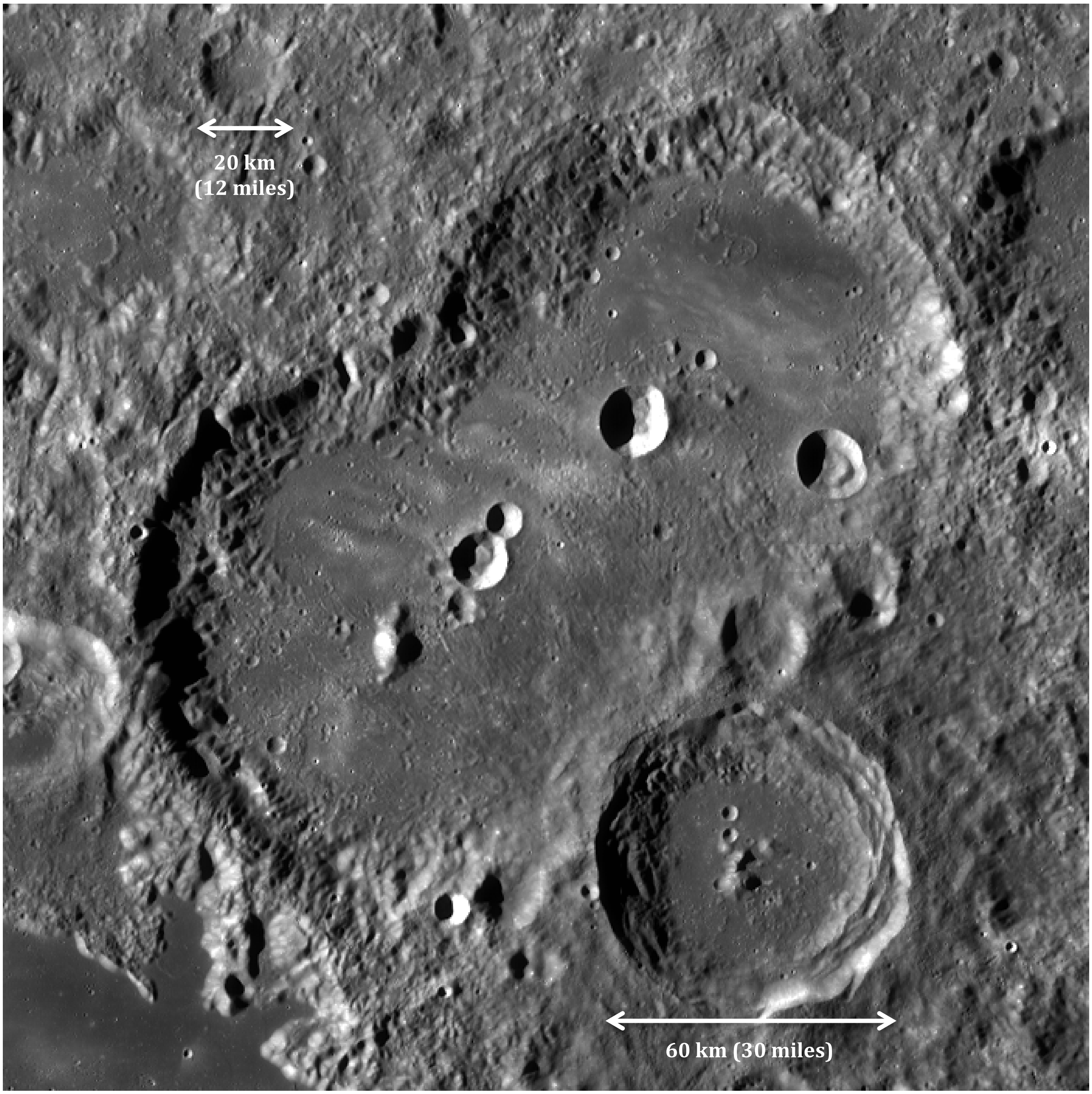
Circle one: northeast northwest southeast southwest upward downward

10. The Islands of Hawai'i are located about 21°N latitude and 158°W longitude. The dominant winds there are called the TRADE WINDS. From which direction would you predict the wind generally blows in Hawai'i?

Circle one: northeast northwest southeast southwest upward downward

Earth's Moon is not a smooth sphere. Close inspection of Earth's Moon reveals jagged, lighter-colored areas, known as the *highlands*. There are also large dark-colored areas, called *maria*, that are curiously smooth in comparison. The entire landscape is marked by circular craters.

The image below is of the *Van de Graff Crater.* This crater is actually composed of two, giant, overlapping craters, that take up most of the image. This figure-8 shape is about 240 km (150 miles) long and 140 km (85 miles) across. Inside are smaller craters that occurred after much more recently. In addition, there is a large 60 km (35 mi) diameter crater on the bottom right that collapsed some of the Van de Graff crater's much older walls.



The majority of these craters were formed billions of years ago, although some are much more recent. Because of limited erosion across our Moon's surface, craters remain largely unchanged over the millennia, except when catastrophically changed by being hit by another impactor.

1. How many craters in the image are more than 50 km (30 mi) across?

Circle one: 1 2 3 5 10 100 1,000

2. How many craters in the image are about 20 km (12 mi) across? (*Hint: include the faint ones around the rims and around the edges*)

Circle one: 1 2 3 5 10 100 1,000

3. How many craters in the image are about 5 km (3 mi) across?

Circle one: 1 2 3 5 10 100 1,000

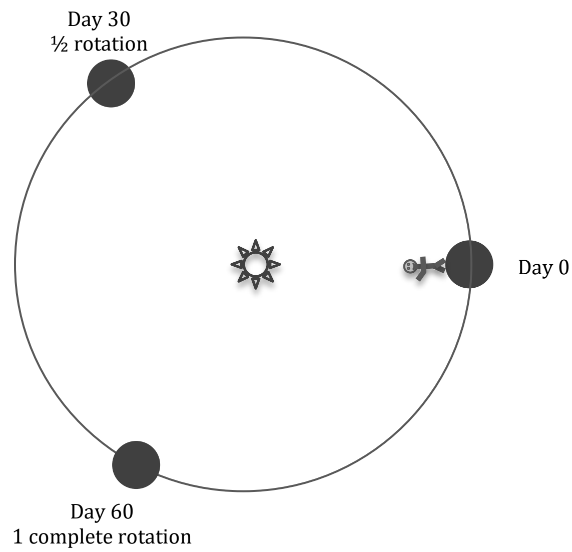
4. How many craters in the image are only a few kilometers (miles across) or smaller?

Circle one: 1 2 3 5 10 100 1,000

5. Write a general "rule" about the relationship among the size of craters and how many there are?

Image Information:
Van De Graaf Crater, Credit: NASA/GSFC/Arizona State University,
http://solarsystem.nasa.gov/multimedia/display.cfm?Category=Planets&IM_ID=15590

Mercury, the planet closest to the Sun, moves very quickly, taking only about 90 days to orbit once. It spins on its axis much slower, taking about 60 days to rotate once. This is known as a 3:2 spin-orbit resonance. (*The precise values are 87.969 and 58.7 days respectively.*)

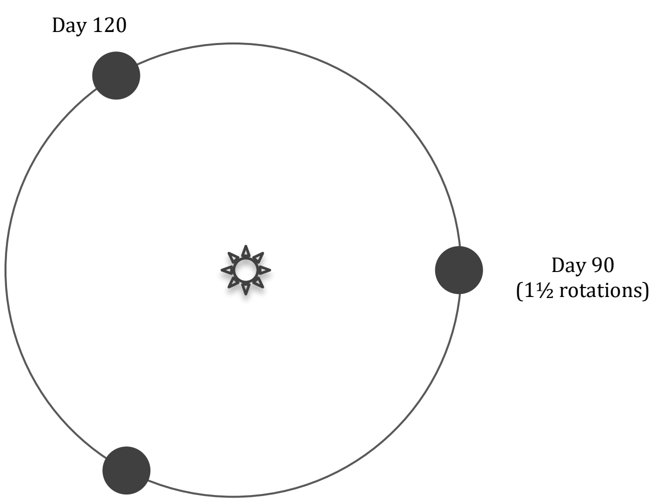


On the Figure at right, a person is shown at Day 0 at the noon position as seen from above the Solar System. *Mercury is both spinning and orbiting counter-clockwise.*

1. Draw the correct location of a person standing on Mercury on Day #30, where Mercury has made ½ of its 60-day spin. *Assume the observer has not moved to a different location on the planet's surface.*

2. Draw a person standing on Mercury on Day #60, where Mercury has made one complete spin.

3. Imagine a student places their figure at the "noon-position" with the Sun overhead. Explain why their sketch is incorrect.



The figure at left now shows Mercury's orbit at a much later time than the figure above.

4. Draw the position of an observer at after 90 days and 1½ rotations.

5. Draw an observer at the 120-day position.

6. How many times has Mercury spun on its axis after 120 days?

Circle one: 1 1½ 2 2½ 3 3½

7. Label the 150-day position and draw an observer.

8. How many days between an observer standing at noon, as shown at the beginning at Day #0, and when the observer returns to the same orientation and position?

Circle one: 30 60 90 120 150 180 210 240 270

9. Why do astronomers describe Mercury as having a 3:2 spin-orbit resonance? *Explain*.

Runaway Greenhouse 24

1. Which of the following planets is closest to the Sun?

Circle one: Mercury Venus Earth Mars

2. Which planet has the highest average temperature at the surface?

Circle one: Mercury Venus Earth Mars

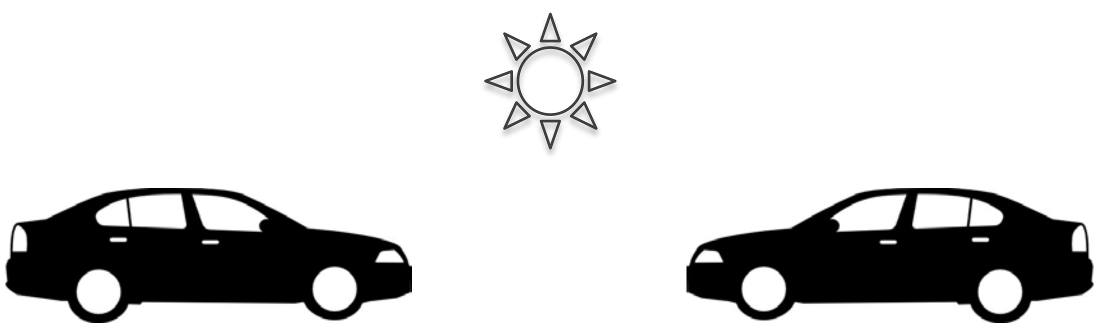
3. Which planet has the thickest atmosphere?

Circle one: Mercury Venus Earth Mars

4. Which planet has the most water?

Circle one: Mercury Venus Earth Mars

5. Image two cars parked on a sunny day. One car has open windows, and the other car's windows are closed. Which car has the greater internal temperature at the end of the day? *Explain*.



Car with windows closed

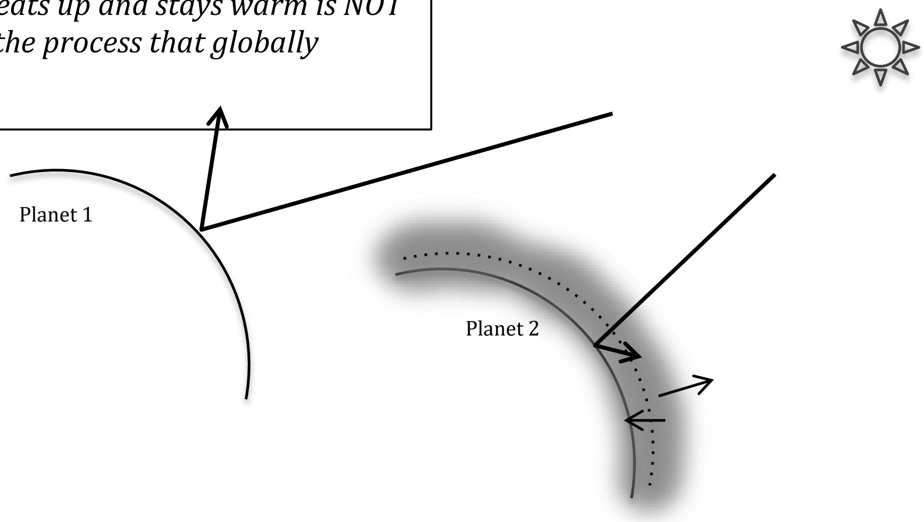
Car with windows open

6. Two astronomers are arguing about why one car is hotter than the other.

> *Astronomer Pat*: Visible wavelengths of sunlight comes in through the windows and heats up the dashboard, the steering wheel, the seats, and the warmed air can't get out.
>
> *Astronomer Chris*: I disagree. The Sun puts off a tremendous amount of heat, which gets shoved into the car by the Sun's energy; but, when it bounces off the car's interior, it doesn't have enough energy to get back out and gets stuck.

With which astronomer do you agree and why? *Explain*.

IMPORTANT IDEA: *The physical process by which a car or a greenhouse heats up and stays warm is NOT precisely the same as the process that globally warms planets.*



7. On Planet #1 (WITHOUT an atmosphere), what happens to the Sun's energy that hits the surface?

Circle one: heats the surface bounces off some bounces & some heats surface

8. On Planet #2 (WITH an atmosphere), what happens to the Sun's energy that hits the planet?

Circle one: heats the surface bounces off some bounces, some heats surface & some heats the atmosphere

9. Each planet receives the same amount of solar energy. Compare the amount of solar energy that escapes each planet.

Circle one: More energy escapes from Planet #1 More energy escapes from Planet #2 There is no difference

10. Which Planet is going to have a higher surface temperature?

Circle one:

Planet #1 Planet #2 There is no difference

11. When objects are heated, their temperatures increase by different amounts, based upon the materials that make them up. This is also true for gases in the atmosphere. Rank the following imaginary planets, from the planet that would gain have the greatest temperature gain to the planet that would experience the smallest temperature increase.

A. Planet with a carbon dioxide atmosphere

B. Planet with a nitrogen atmosphere

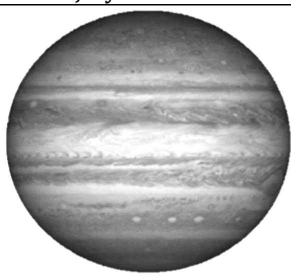
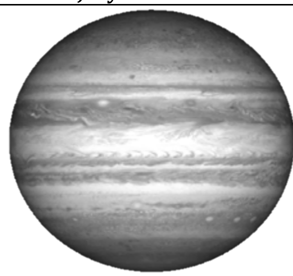
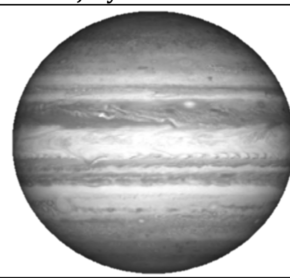
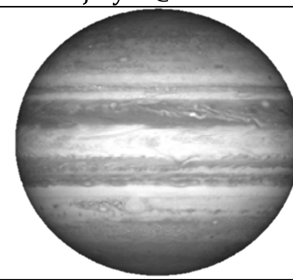
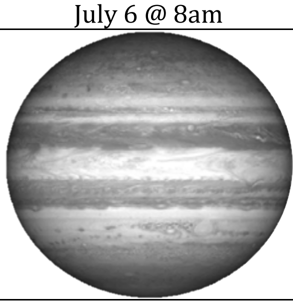
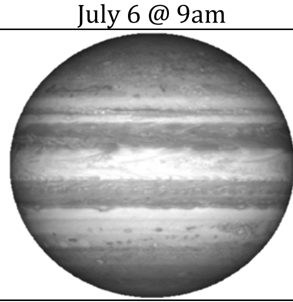
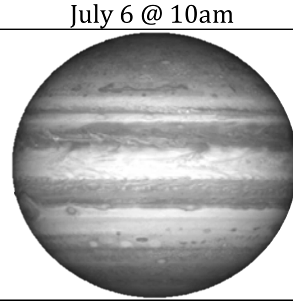
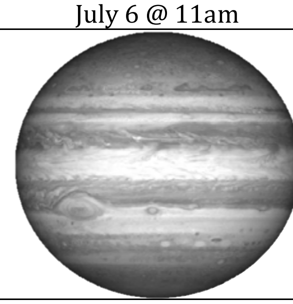
C. Planet with a methane atmosphere

Greatest Temperature Increase	______ ______ ______	Smallest Temperature Increase

Rotation of Jupiter 25

1. Below are 12 images of Jupiter taken on different dates and different times. As precisely as you can, determine the number of hours and minutes Jupiter takes to spin once.

Images from NASA/JPL Solar System Simulator, http:// http://space.jpl.nasa.gov/, Credit: NASA/JPL/CalTech

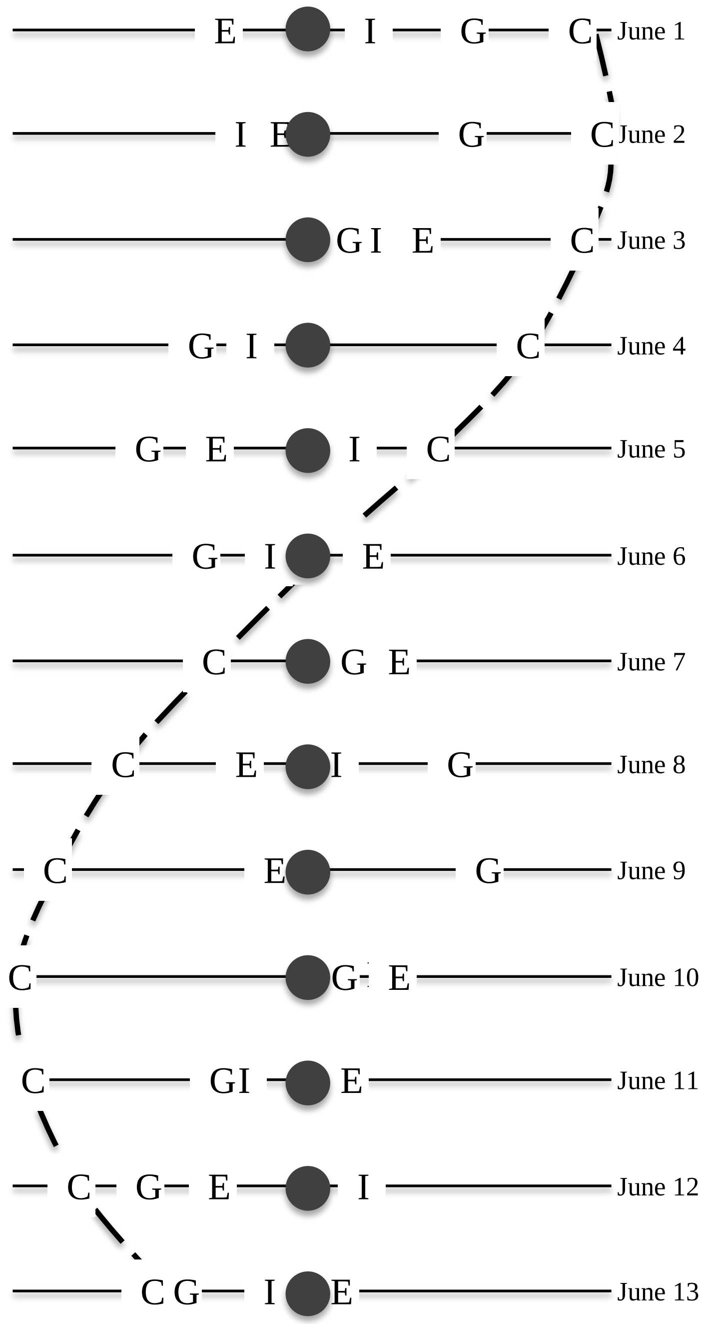
			
July 6 @ 4am	July 6 @ 5am	July 6 @ 6am	July 6 @ 7am
			
July 6 @ 8am	July 6 @ 9am	July 6 @ 10am	July 6 @ 11am
			
July 6 @ 12pm	July 6 @ 1pm	July 6 @ 2pm	July 6 @ 3pm

2. Explain how you came up with your rotational period. *Provide enough detail so that someone else could use your strategy*.

3. Find at least two other people/groups who came up with a rotation period (hours and minutes) and compare your answer with theirs.

Alternate Answer #1: ___________ Alternate Answer #2: ___________

The Figure at right shows Jupiter and the day to day changing positions of Jupiter's moons, Io, Europa, Ganymede, and Callisto.



4. Looking first at Calisto, how long does it take to orbit all the way around Jupiter once?

Callisto's orbital period: ____________

5. Drawing a smooth line dot-to-dot for the positions for Ganymede, determine its orbital period.

Ganymede's orbital period: ____________

6. Drawing a smooth line dot-to-dot for the positions for Europa, determine its orbital period.

Europa's orbital period: ____________

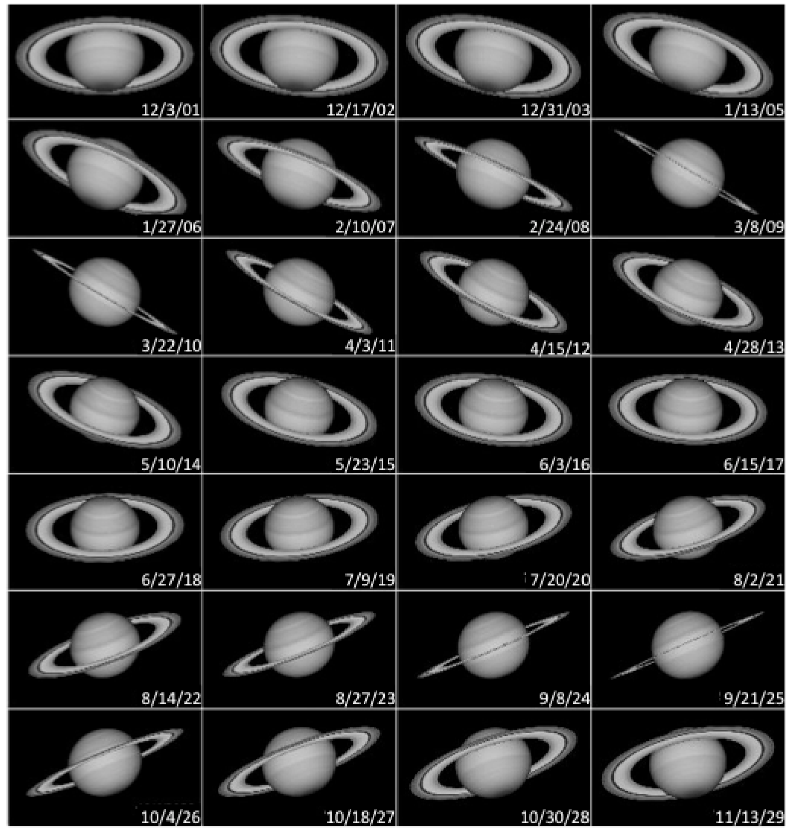
7. Drawing a smooth line dot-to-dot for the positions for Io, determine its orbital period.

Io's orbital period: ____________

8. Why are less than four moons visible on some days?

Saturn's Rings 26

Saturn's majestic ring system has fascinated astronomers since they were first observed hundreds of years ago. It's a complex system, in which the planet's motion cause changes in its appearance.



(Saturn 2001-2029 adapted from simulations by Tom Ruen for public domain under CC BY-SA 3.0)

1. Saturn's wide rings are incredibly thin, so much so that they can seem to disappear. In which years were Saturn's rings nearly invisible as seen from Earth?

2. For the observations listed, in which year were Saturn's rings most easily visible?

3. How many years between Saturn's ring's disappearances.

5. Saturn takes about 29 years to orbit the Sun once. How long does it take Saturn to go ½ way around?

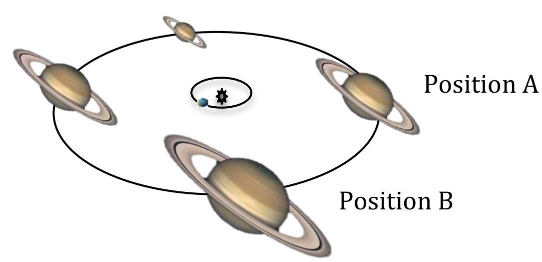
6. How long does it take Saturn to go ¼ of the way around in its orbit?

7. What do Saturn's rings look like at Position A?

Circle one: Broadside Nearly invisible

8. What do Saturn's rings look like at Position B?

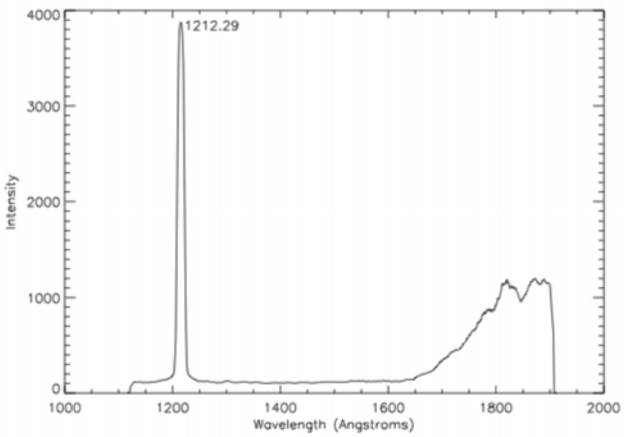
Circle one: Broadside Nearly invisible



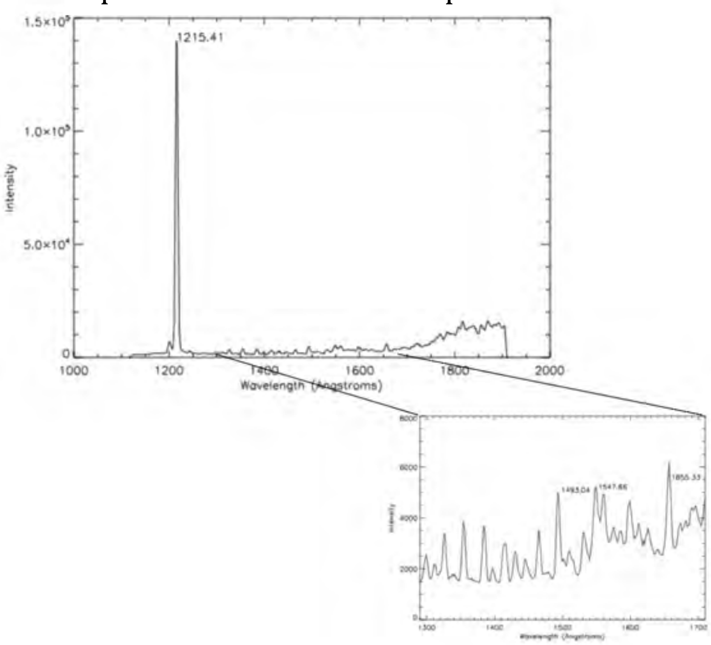
9. Why do Saturn's rings "nearly disappear" regularly?

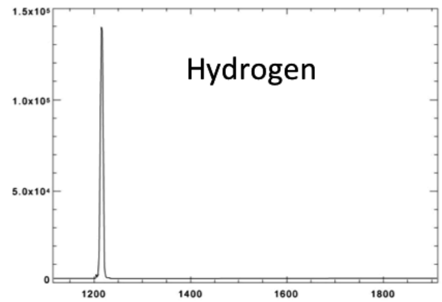
The following spectra were taken by NASA's Cassini-Huygens on its mission to explore Saturn and its moons, including the moon Titan. The observed spectra are on the left side of the page. The spectra of four elements are given on the right side of the page.

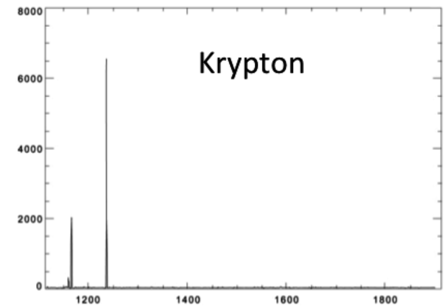
Spectrum of Saturn's Rings

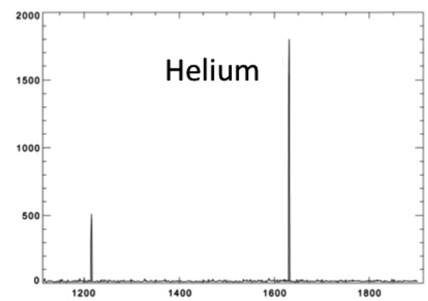


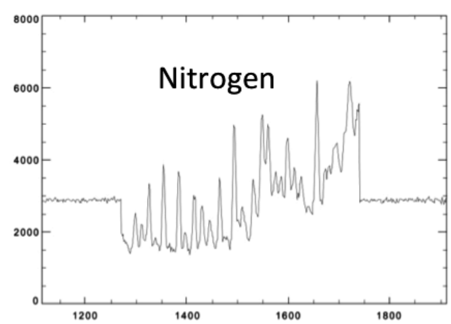
Spectrum of Titan's Atmosphere











10. What element(s) can we observe in Saturn's rings?

11. What element(s) can we observe in Titan's atmosphere?

12. If you were allowed to take observations to search for one other element in Titan's atmosphere, which element would you choose?

Most of the planets spin and orbit in the same direction around the Sun—counterclockwise. There are, however, some variations. You might already know that Earth's axis of rotation isn't straight up and down, but tilted at 23½°. Uranus is quite odd, seeming to be laying on it's side, 97° from an upright position. *Venus might be the strangest of all, being titled at 177°, making it almost upside down.*

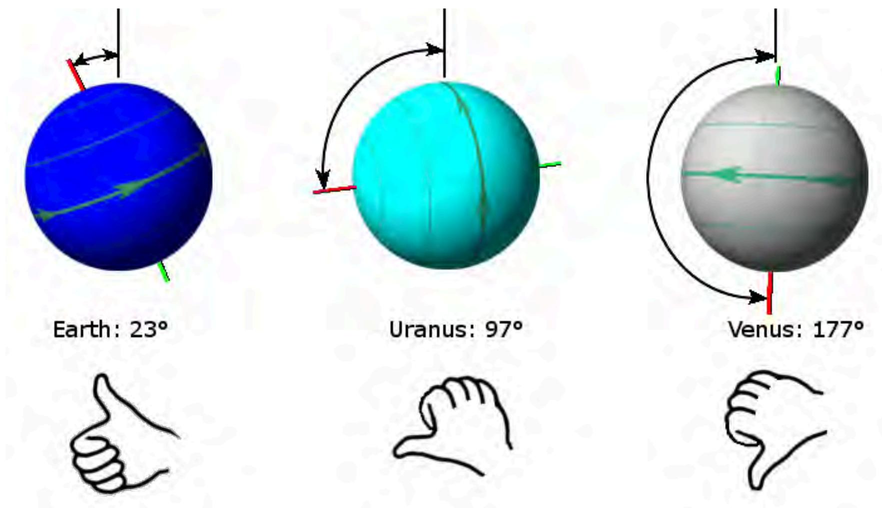
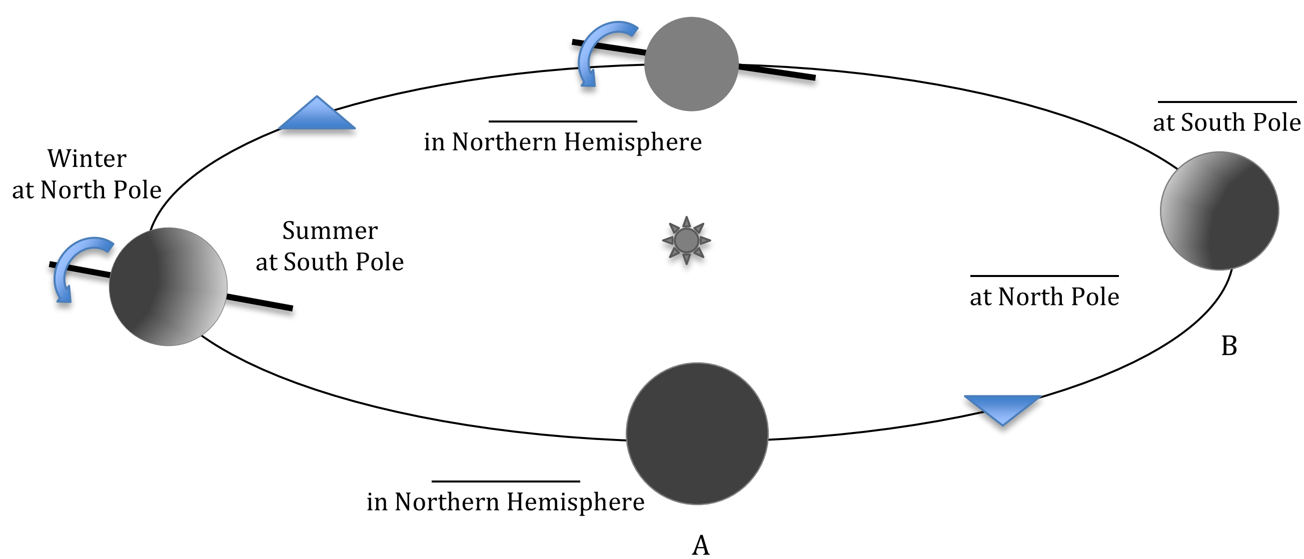


Image from adapted from https://en.wikipedia.org/wiki/Axial_tilt#/media/File:Planet_axis_comparison.png under CC BY-SA 3.0

1. Below is a partially completed drawing of Uranus orbiting the Sun with the axis of rotation shown. Draw and label Uranus' rotation axes at Positions A & B. Write the correct season on each blank line.



2. The star directly above Uranus' north pole is called *15-Ori*. Draw an arrow on the figure pointing toward *15-Ori.*

3. Uranus takes 84 years to orbit the Sun once. How long does summer last?

Circle one: 0 yrs 21 yrs 42 yrs 63 yrs 84 yrs

Often, people think about planets wobbling around erratically like a spinning top running out of energy. Except over thousands of years, the direction a planet's axis points doesn't change much. Earth's axis, for example, points toward Polaris, the North Star. Uranus' points toward 15-Ori.

4. Two astronomers are arguing about how Uranus moves in its orbit.

> *Astronomer Pat*: Uranus seems to be rolling through space as it moves around the Sun. The northern pole is always pointed at the Sun so one side is always shining in daylight and the other always in permanent darkness.
>
> *Astronomer Chris*: That can't be true. I think on Uranus experience 21years of permanent daylight where the Sun doesn't set, 21 years of day/night cycles, and then 21 years of permanent nighttime, so its rotational axis must point at a different star.

With which astronomer do you agree and why? *Explain*.

Brightness of the Sun at Planets

How bright is a sun-shiny day on planets other than Earth? The size of the Sun looks smaller the farther away you observe it, following a 1-to-1 rule for size. If you are at Jupiter, five times farther away from the Sun as Earth, it only looks $^1/_5$ as big.

The intensity of light decreases with distance too; however, light follows a different rule because light spreads out as it moves through outer space. The precise amount of sunlight hitting planets decreases with the square of the distance, *r*—this rule is known as a $^1/_{r^2}$ relationship.

1. Complete the table below using the 1-to-1 rule for size and the $^1/_{r^2}$ rule for light intensity. *Hint: Do the outer planets first, then come back to the inner planets.*

Object	Approximate Distance in AU (*Earth distances*)	Size of Sun (*compared to seen at Earth*)	Sunlight Intensity (*compared to seen at Earth*)
Mercury	0.4		
Venus	0.7		
Earth	1.0	1x	1x
Mars	1.5		
Ceres	3		
Jupiter	5		
Saturn	10		
Uranus	20		
Neptune	30		
Pluto	40		

2. When standing on Earth, the Sun is about the same size as your thumbnail at arm's length. How big would the Sun appear if you were at Saturn?

Circle one: closed fist pencil diameter spaghetti diameter human hair diameter

3. Compare the Sun's apparent size from Jupiter and from Saturn.

4. How much less bright of a sunny day is it on Saturn as compared to standing on Jupiter?

5. How much brighter is the noontime Sun on Uranus compared to Neptune?

In July of 2015, the New Horizons spacecraft finally made it to Pluto, traveling about 3.6 billion miles (5.8 billion kilometers) at about 36,000 mph (58,000 kph) for about 9.5 years. *That's a really long way, at a super high speed, for a very long time.*

Messages to and from the spacecraft travel much faster than the spacecraft itself, but they are not instantaneous. Pictures of Pluto come back from the spacecraft traveling at the speed of light, about 186 miles per second (300,000 kilometers per second). Even at that high speed, it takes quite a while for messages to get back and forth between Earth and the spacecraft.

The Sun is 93 million miles away, and at light speed it takes 8.3 minutes (8 minutes and 18 seconds) for sunlight to get to Earth. For the following problems use the approximation that the light travel time between Earth and the Sun is 10 minutes.

1. Complete the following table without a calculator.

Object	Approximate Distance in AU (*Earth distances*)	Light Travel Time Between the Object and the Sun *(using 10-min for Sun-Earth travel time)*
Mercury	0.4	
Venus	0.7	
Earth	1.0	10 min.
Mars	1.5	
Jupiter	5	
Saturn	10	
Uranus	20	
Neptune	30	
Pluto	40	

2. About how much longer does it take for a radio signal from Earth take to get to Pluto, as compared to Jupiter?

3. About how long does it take a radio signal to get from Earth to Mars when they are close together?

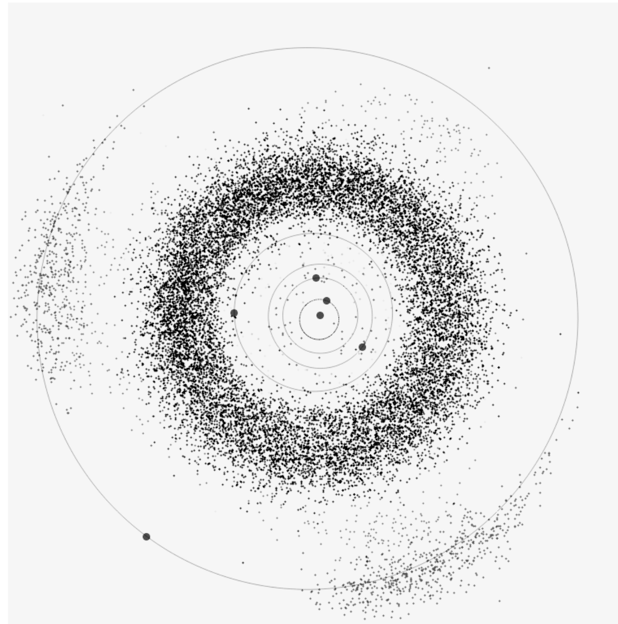
4. If Earth and Mars are on opposite sides of the Sun, about how long does it take a radio signal to get between the two?

5. When determining about how long it takes to send messages to Pluto, we don't often worry if Pluto is on the same, near side of the Sun as Earth is or not. Why is this reasonable?

6. If we send a "take a picture now" message to the New Horizons spacecraft at Pluto, how long before we get a message back (assuming that there is no processing time).

7. If New Horizon's sends a very short "help" message back to Earth, how long must it wait to hear back from us?

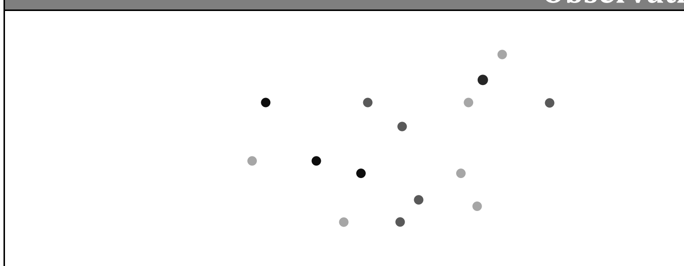
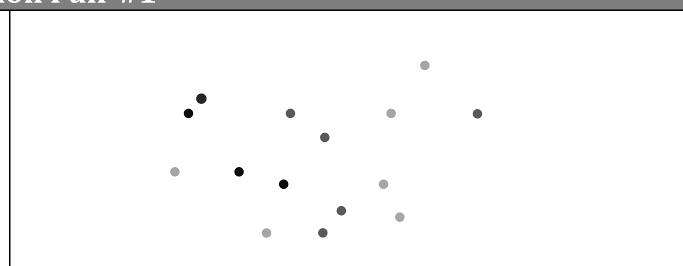
A feature of our Solar System is a ring of asteroids; most asteroids are orbiting between the orbital paths of Mars and Jupiter. Asteroids are important because they were mostly formed at the beginning of our Solar System, and provide clues to the initial chemistry of formation.



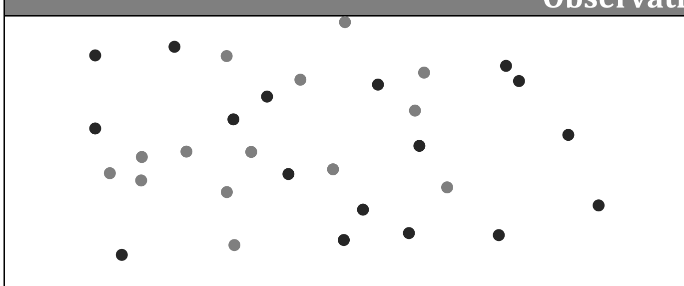
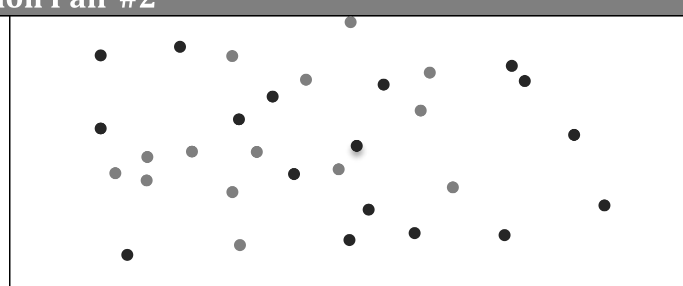
The picture at right is a map showing the locations of known asteroids. The Sun is at the center, and the largest dots indicate the locations of our Sun, Mercury, Venus, Earth, Mars, and Jupiter.

Asteroids are often discovered by taking pictures of the night sky at different times. The stars will all appear in essentially same place, but the "dot" that moves in front of the distant—that's an asteroid!

1. Circle the asteroid in the first set of images below.

Observation Pair #1	
	
Star field #1 (*before*)	Star field #2 (*after*)

2. Circle the asteroid in the second set of images below.

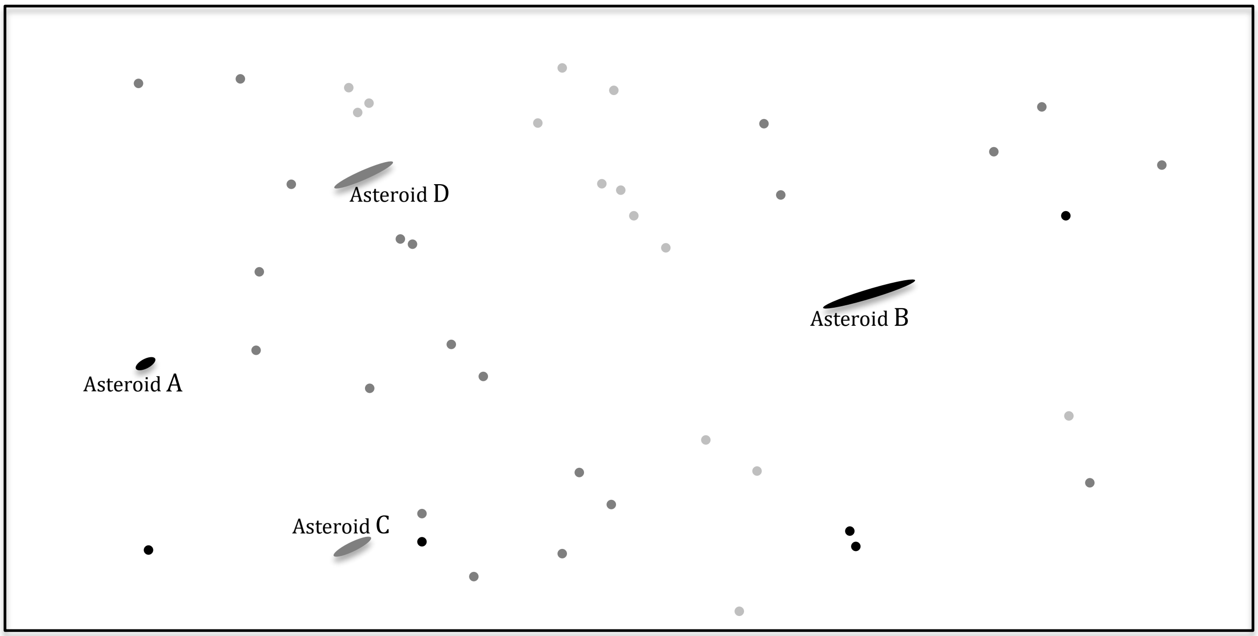
Observation Pair #2	
	
Star field #A (*before*)	Star field #B (*after*)

3. Using what you've learned earlier about the rules of planetary motion developed by Johannes Kepler, which is the asteroid closer to the Sun? *Explain*.

Another strategy for finding asteroids is to take a long-exposure picture of the stars and look for an object that is moving—it shows up as a streak. The length of the streak indicates how fast the asteroid is moving and provides an estimate for how far away it is.

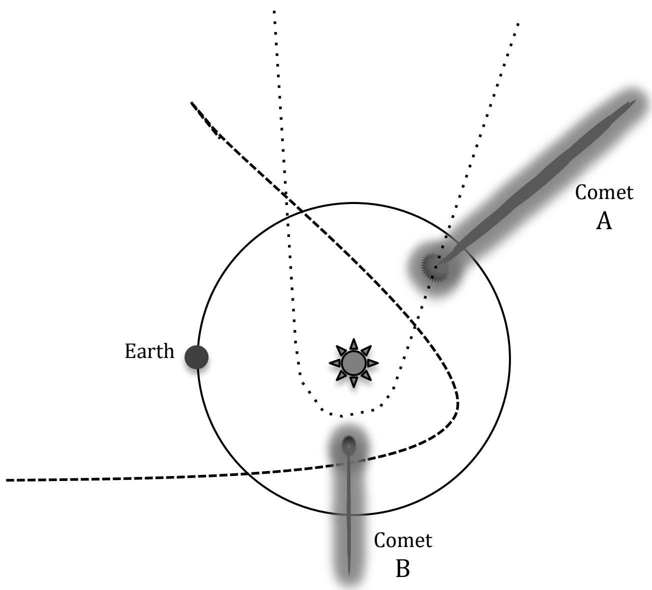
4. Rank of the asteroids found in this image from nearest to farthest.

Nearest <- ________ ________ ________ ________ -> Farthest



Whereas shooting stars zip across the sky in a matter of seconds, comets are distant objects that appear to move quite slowly. In stark contrast to shooting stars, comets can often be observed for weeks or even months as they slowly make their way toward and away from the Sun. The size of the comet and its relative position to the Sun and Earth determines how easy it is to see a comet.

The Figure below shows the orbits of two comets and Earth around the Sun, as seen from above. (*As usual, these conceptual illustrations are not to scale.*)



1. When is this Comet A going to best be visible?

Circle one: anytime midnight near sunrise near sunset

2. When is this Comet B going to best be visible?

Circle one: anytime midnight near sunrise near sunset

3. Which comet tail is the longest?

Circle one: Comet A Comet B

4. Which comet tail appears to be the longest as seen from Earth?

Circle one: Comet A Comet B

5. Two astronomers are arguing about studying comets.

> *Astronomer Pat*: Comets are best observed at midnight when it is dark and they are far from the Sun's glare.
>
> *Astronomer Chris*: I disagree. Comets are best observed when they are closer to the Sun because their tails are bigger because of the Sun's energy.

With which astronomer do you agree and why? *Explain*.

The Figure below shows Earth's and Comet Halley's orbits around the Sun as seen from above.

6. Comet Halley reached perihelion (point closest to the Sun) on April 20, 1910. Was it an impressive appearance with a long tail seen broadside?

Circle one: Yes, tail appeared long No, tail appeared short

7. What time of day was Comet Halley best observed in April of 1910?

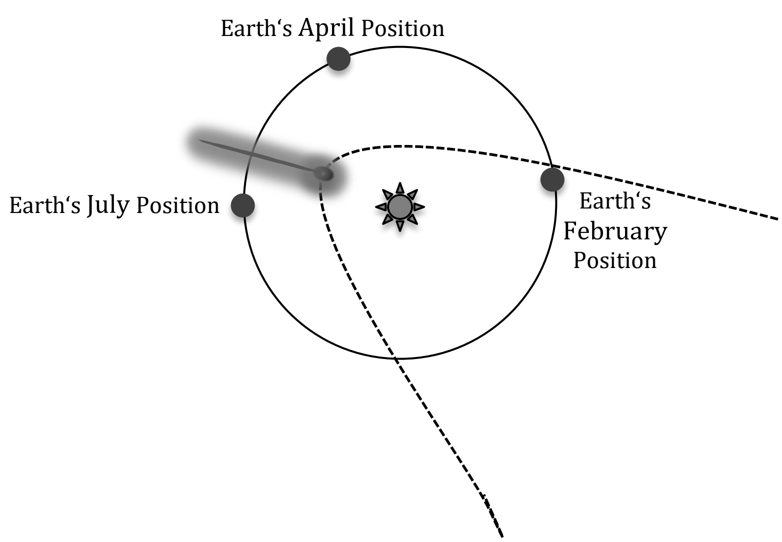
Circle one: anytime midnight near sunrise near sunset

8. Comet Halley reached perihelion (point closest to the Sun) on February 9, 1986. Was it an impressive appearance, with a long tail seen broadside?

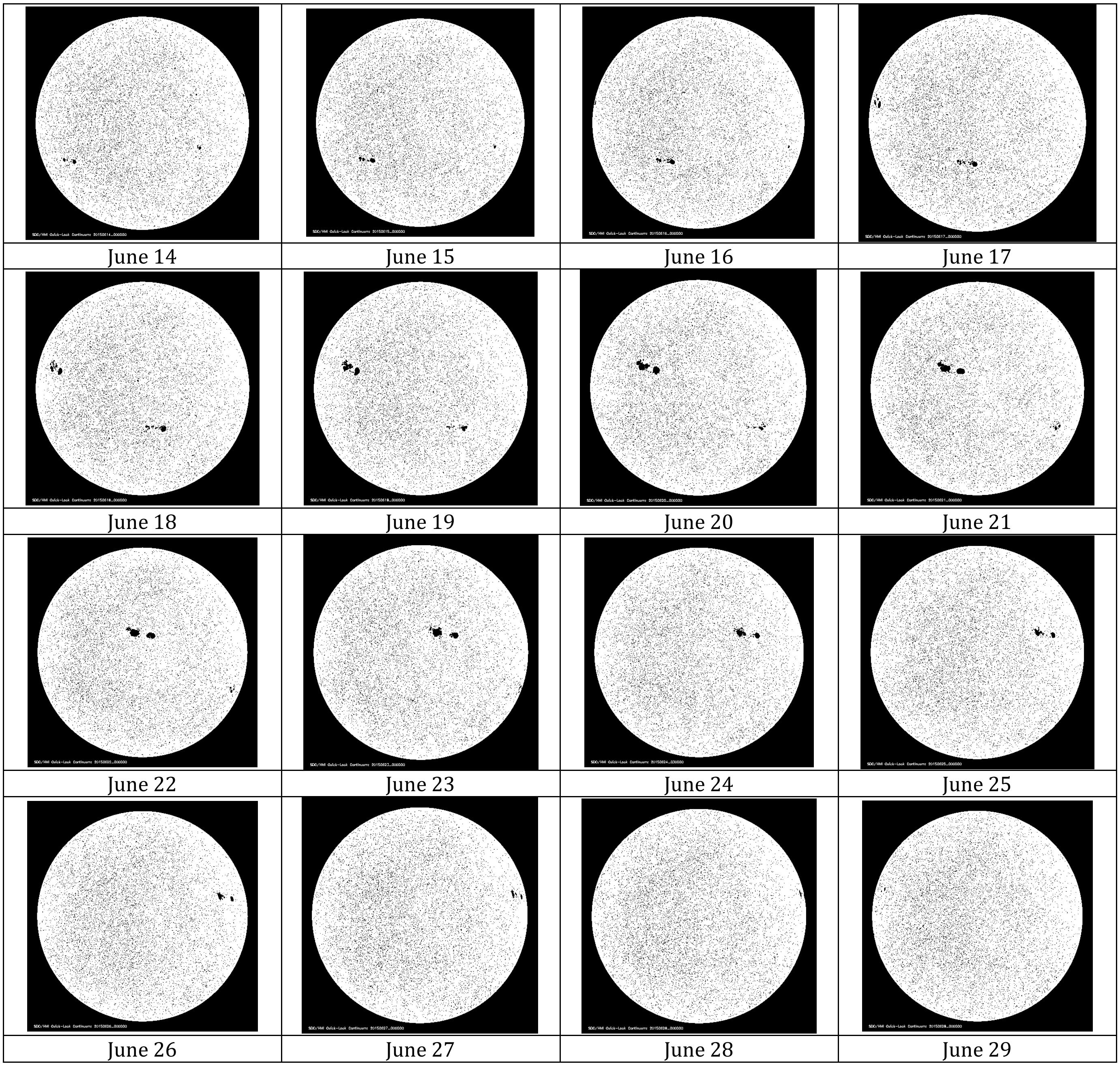
Circle one: Yes, tail appeared long No, tail appeared short

9. Comet Halley reached perihelion (point closest to the Sun) on July 28, 2061. Was it an impressive appearance with a long tail seen broadside?

Circle one: Yes, tail appeared long No, tail appeared short



The Sun and Stars



2015 Images from http://soho.nascom.nasa.gov/data/realtime-images.html

1. The Sun is quite large. If 109 Earths (🌎) would fit across the face, about how big are the sunspots seen on June 22?

Circle one: smaller than Earth   about same as Earth   larger than Earth

2. Which way does the Sun spin in these images?

Circle one: left to right   right to left

3. Seen from above the Solar System, the Sun spins

Circle one: counter-clockwise (*same as Earth's spin*)   clockwise (*opposite of Earth's spin*)

4. About how many days does it take the sunspots just barely visible along the Sun's limb on June 16 to move to the middle of the Sun's face?

Circle one: 1 2 3 4 5 6 7

5. On what date do those sunspots disappear from view on the opposite limb of the Sun?

Circle one: June 23 June 27 June 29

6. About how many days do you think it would take those sunspots to come back around to be visible again—if they survive that long?

Circle one: 7 13 25 365

7. About how many days does it take the Sun to spin on its axis?

Circle one: 7 13 25 365

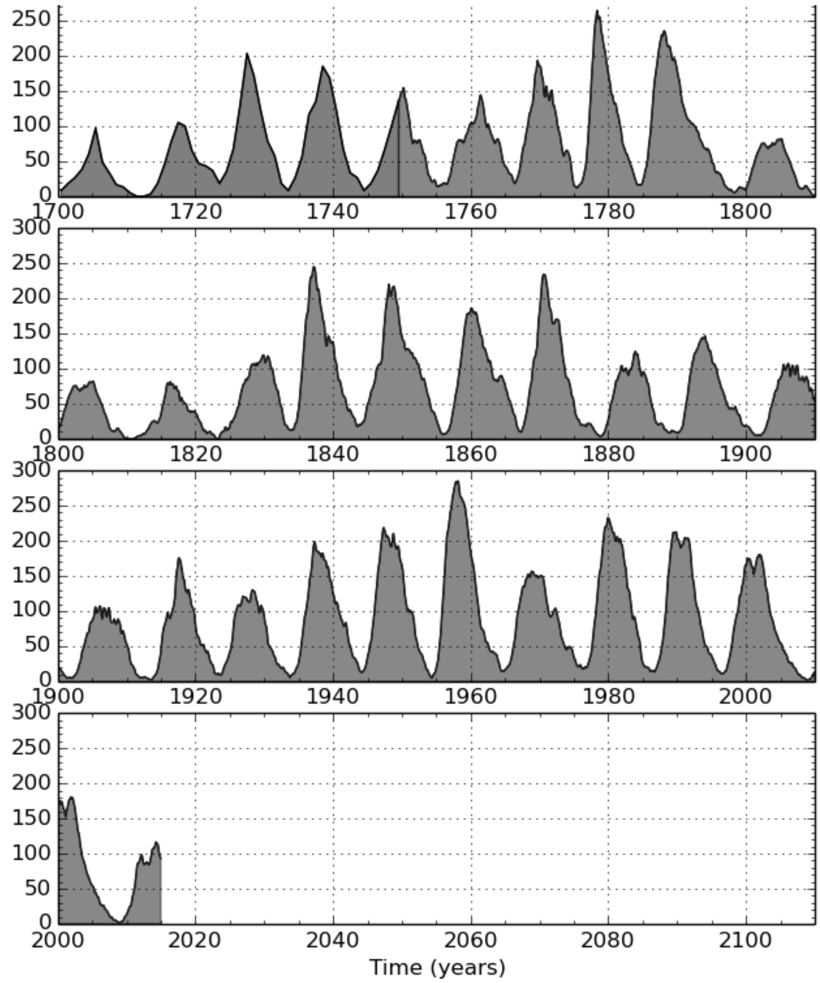
8. The northern lights (aurora) are created when highly charged particles are released from the Sun near sunspots. On which date are the sunspots aligned directly with us?

Circle one: June 17 June 22 June 25

9. If a brilliant aurora was reportedly observed on Earth on June 25, about how long did it take the materials ejected from the Sun to arrive at Earth?

Circle one: 8 minutes 3 days 25 days 1 month 1 year

The Sun cycles through periods of very little sunspot activity and periods of substantial sunspot activity. Predicting times of maximum solar activity—called solar maximum—is critical. When many sunspots on seen on Sun, Earth experiences northern lights (aurora), unpredictable electrical outages, dangerous conditions for space-walking astronauts, and an inflated atmosphere that can change the orbital paths of Earth's satellites.



The Figure at right shows how sunspot numbers vary year after year.

1. When was the most recent solar maximum? *Circle one*:

2014 2008 2000 1996 1989

2. When was the solar maximum before that? *Circle one*:

2008 2000 1996 1989 1986

3. A solar cycle is the time from one minimum to the next. When did the most recent cycle start? *Circle one*:

2014 2008 2000 1996 1989

4. On average, the time between minima is about 11-years. When do you predict the next minima will be?

5. Over the last 300 years, which year had the largest sunspot count? *Circle one*:

2014 1960 1840 1780

6. Was the most recent cycle a strong one, compared to the typical solar maximum?

Circle one: strong average weak

7. What was solar activity like in the year you were born?

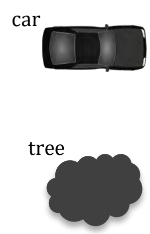
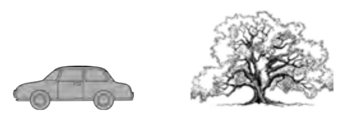
8. Make a prediction about the sunspot number for next year.

Circle one: higher about the same lower

Credit: SILSO data/image, Royal Observatory of Belgium, Brussels. Updates available from http://www.sidc.be/silso/datafiles

Updated minimum and maximum solar cycle dates available at: https://en.wikipedia.org/wiki/List_of_solar_cycles

When looking into the night sky, it might appear as if all stars are the same distance from us. As it turns out, some stars are close but most are far away. The distances to nearby stars can be measured using the strategy of parallax.

 Point A Point C Point B		
Overhead, top-view	View from Point A	View from Point B

The figure above shows a car and a tree as seen from several vantage points.

1. If viewed from Point C in the center, the car appears
Circle one: in front of tree   behind the tree   to one side of the tree

2. When viewed from Point A, the car appears
Circle one: to the right of the tree   behind the tree (*hidden*)   to the left of the tree

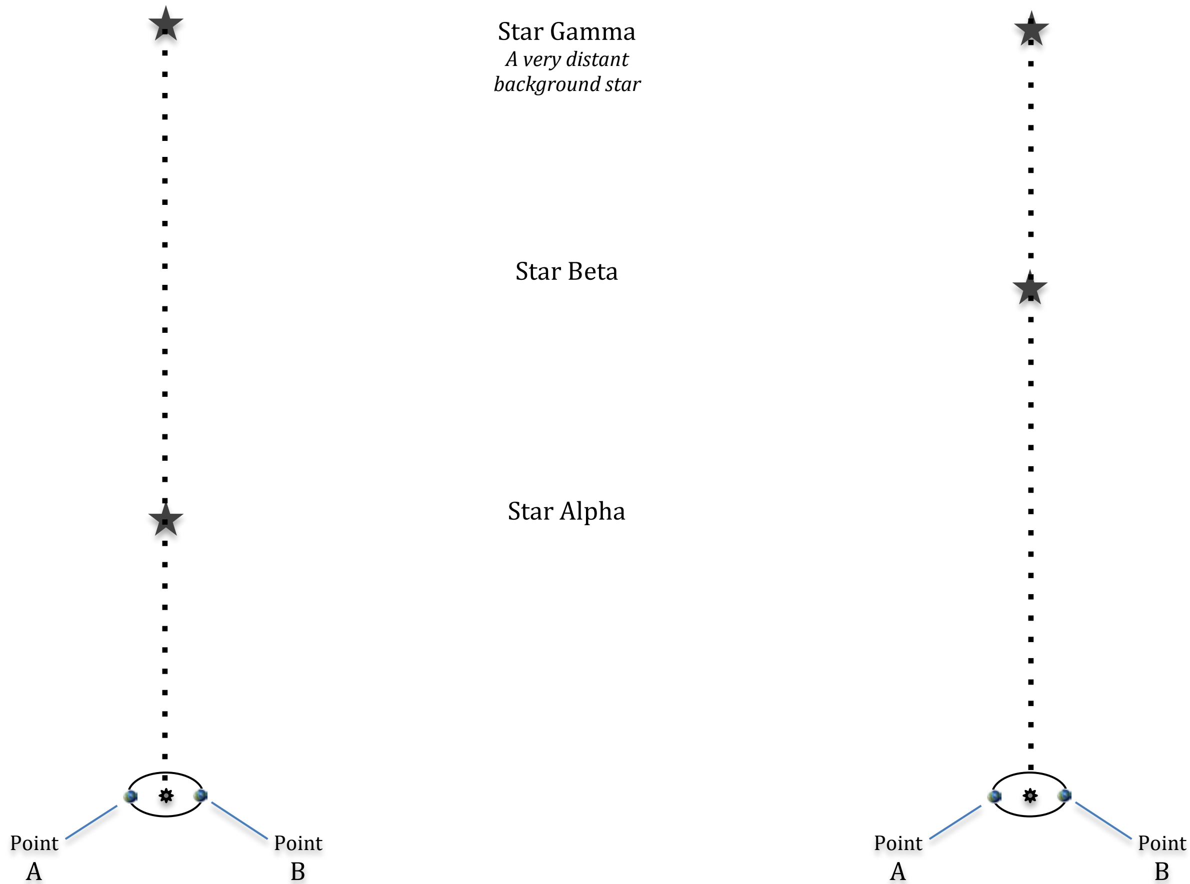
3. Draw the car and tree as seen from Point B in the figure above.

4. Imagine instead that the distance between the car and the tree is large. How does your view from Point B change?

5. Two astronomers are arguing about parallax.

> *Astronomer Pat*: I think that the only difference in the View from Point B when the tree and car are farther apart is that the car would appear smaller, because it is farther away.
>
> *Astronomer Chris*: I agree, the car would be a little smaller, but the two objects would appear farther apart too, and have a wider angle between them.

With which astronomer do you agree? *Circle one*:   Pat   Chris



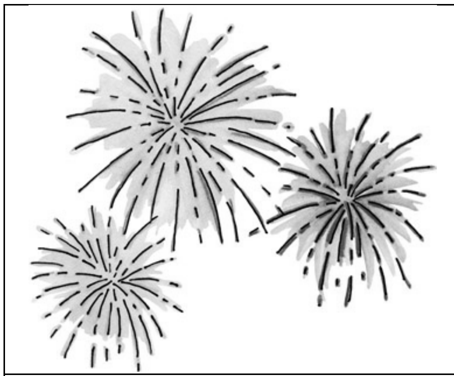
6. In the space below, draw and label what nearby Star Alpha and very distant Star Gamma (shown above on the left) would look from Points A and B

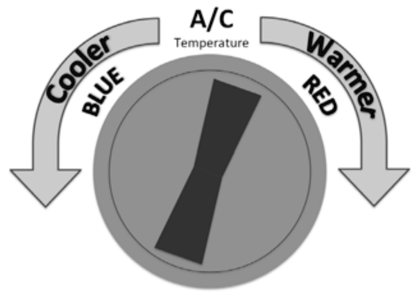
View from Point A	View from Point B

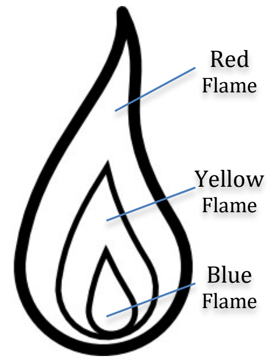
7. In the space below, draw and label what farther Star Beta and very distant Star Gamma (shown above on the right) would look like from Points A and B

View from Point A	View from Point B

8. What the general rule about the apparent parallax angle between the nearest stars (like Star Alpha) and the more distant stars, compared to farther away stars, like Star Beta?







FIREWORKS	TEMPERATURE CONTROL DIAL	FLAME
Circle One Process: A B C	*Circle One Process*: A B C	*Circle One Process*: A B C

1. The chart above lists colored objects resulting from three very different processes. Complete the third row of the table by matching the process with the correct drawing.

Process A: When human skin gets hot, the red blood carrying capillaries move toward the surface causing your skin to appear red

Process B: The hottest part of a fire releases blue-appearing, higher energy light, whereas the cooler parts of the flame emits red-appearing, lower energy light

Process C: When different chemicals rapidly burn, they emit characteristic colors (*strontium carbonate burns red, barium chloride burns green, and copper chloride burns blue*)

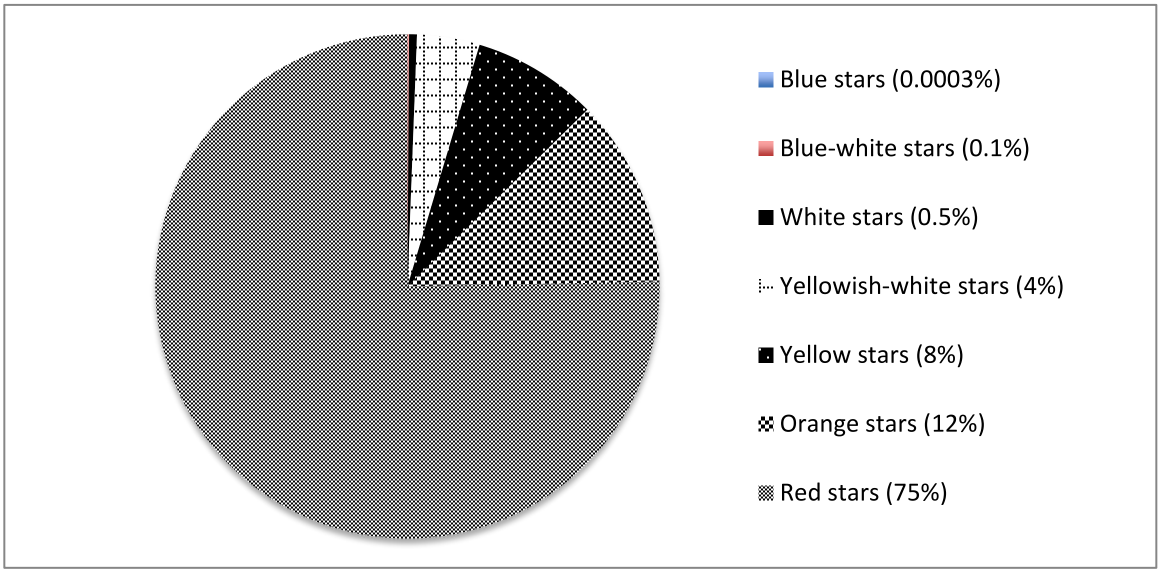
2. Stars shine using *NONE* of the processes above. Instead, stars shine because the high temperature substance making up stars glows when heated. Knowing that higher temperature stars release higher-energy, longer-wavelength light, rank the glowing stars below from hottest to coolest.

Hottest ← __________ __________ __________ __________ __________ → Coolest

●	●	●	●	●
Red Star	Blue Star	Yellow Star	Orange Star	Yellowish-white

Some stars put out lots of each color because of their medium temperature, overpowering emitted green light and making them appear yellowish-white.

When we carefully look around the sky, we see the following rough distribution of star colors. (*The precise values are subject to considerable debate among astronomers.*)



3. The Sun is a yellow star. It is similar to about what fraction of stars in the sky?

Circle one: 75% 12% 8% 4% >1%

4. Most of the stars are in the sky are

Circle one: low temperature stars medium temperature high temperature

5. The most rare stars in the sky are

Circle one: blue stars white stars red stars

6. Two astronomers are arguing about the nature of stars.

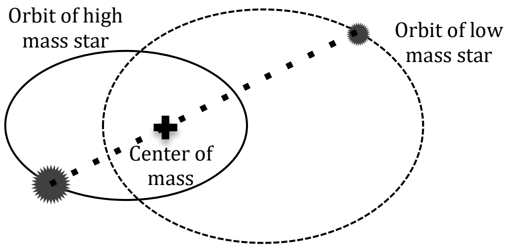
Astronomer Pat: The Sun is an average star: It is like most of the stars in the sky.

Astronomer Chris: Well, the Sun has an average temperature compared to other stars, but the Sun is not average in terms of being representative of most of the stars.

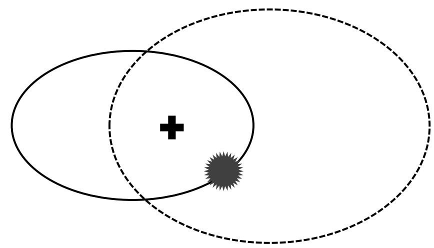
Which astronomer do you agree with and why? *Explain*.

The vast majority of the stars in our galaxy are small, isolated red stars. However, to our great surprise, when we look at nearby stars like the Sun, we find that about half of them are not isolated, but instead exist in binary 2-star pairs, triplet 3-star systems, or even larger groups. For the hottest stars, it might be as many as 85% are members of multiple-stars systems.

Binary star pairs form simultaneously from different areas of the same gigantic parent cloud. The stars orbit around a common center of mass due to their shared gravitational attraction.



Time #1



Time #2

1. Draw the position of the low mass star on the right-hand side of the diagram above at Time #2. *A line through the center of mass always connects the two stars*.

2. Which star moves fastest in its orbit?

Circle one: the star with the largest orbit the star with the smallest orbit

3. Which star takes the longest amount of time to make one orbit?

Circle one: high mass star low mass star the times are equal

4. Two astronomers are arguing about the orbits of binary stars.

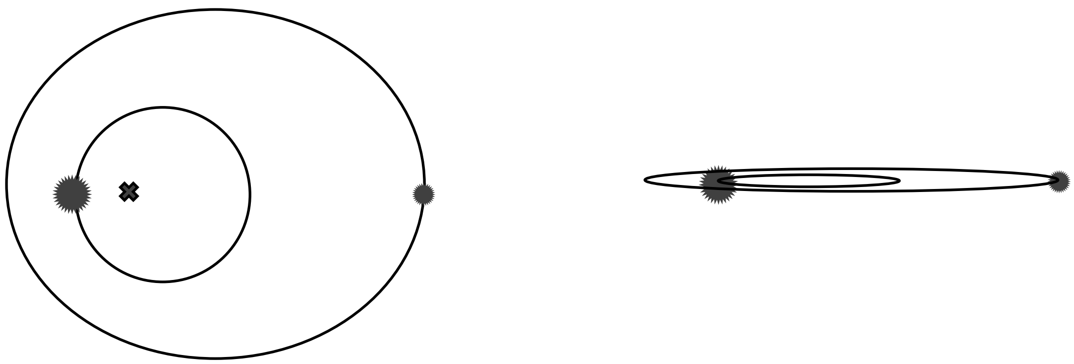
> *Astronomer Pat*: I think that stars are moving slowest and spending most of their time widely separated when far from their center of mass because of Kepler's Laws of Planetary Motion.
>
> *Astronomer Chris*: I disagree. I think that the two stars will spend most of their time close together because of Newton's Laws of Gravitation.

Which astronomer do you agree with and why? *Explain*.

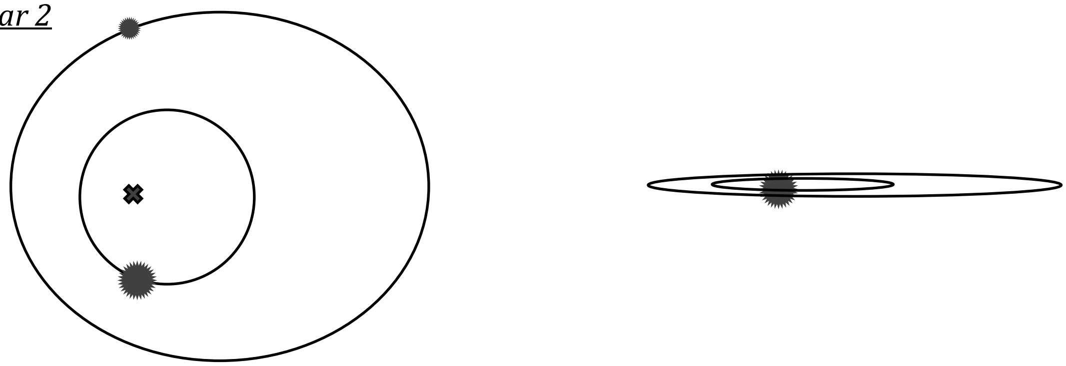
4. On the next page, two stars are orbiting a central point. For Years 2 & 3, draw the position of the smaller star and on the graph at the bottom, draw the total light curve for the three-year period.

Overhead Top-View Side-View

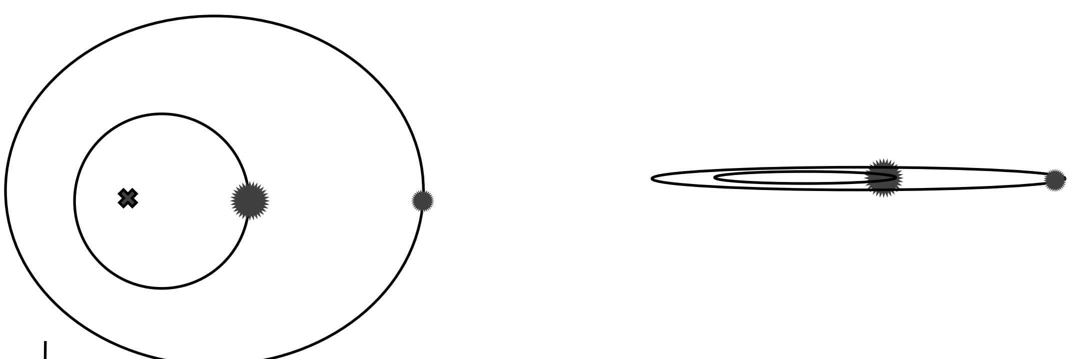
Year 1

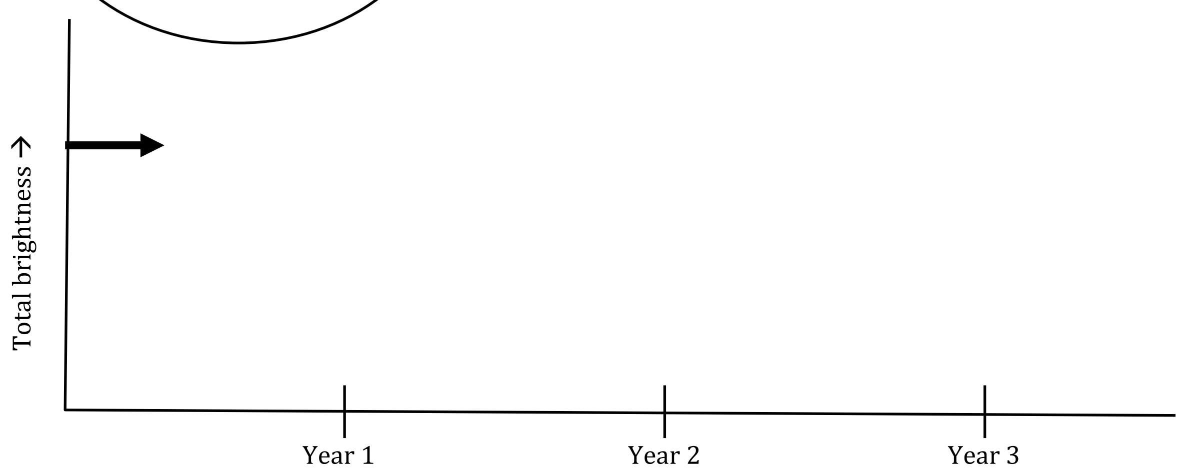


Year 2



Year 3





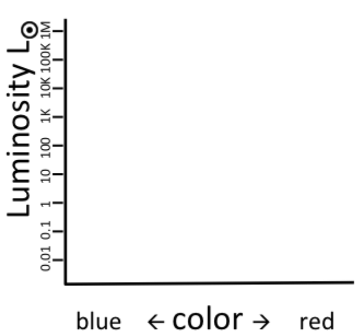
Stellar Masses 38

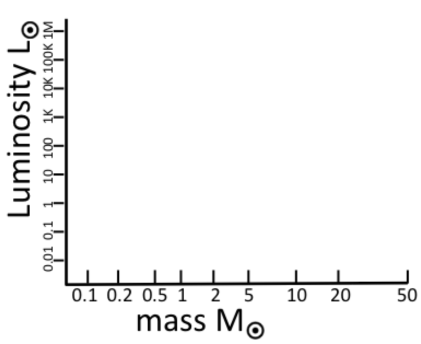
Astronomers have painstakingly observed stars many years to construct a database comparing stars' masses, colors, and brightnesses. A sample are listed in the table below.

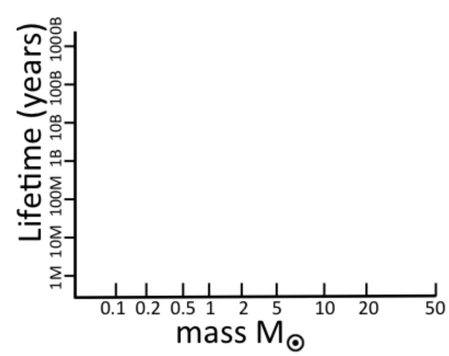
Example Stars	Luminosity, $L_\odot$ (in Sun's)	Color	Mass, $M_\odot$ (in Sun's)	Radius, $R_\odot$ (in Sun's)	Lifetime (Est. Years)
Proxima Centauri	0.002 (0.2%)	Dark Red	0.12 (12%)	0.14 (14%)	100's of billions
Epsilon Indi	.22 (22%)	Orange	.76 (76%)	.73 (73%)	30 billion
Sun (Sol)	1.0	Yellow	1.0	1.0	10 billion
Gamma Virgo	6 ½	Yellow-White	1 ½	1 ½	3 billion
Vega (Alpha Lyra)	40	White	2	2 ½	400 million
Tau Scorpius	18,000	White-ish Blue	15	10	30 million
Rigel	120,000	Blue-ish White	20	15	15 million
Zeta Pupis	750,000	Blue	50	25	3 million

* *These numbers are highly simplified*

1. Sketch graphs for the following: L *vs* color; L *vs* m; and Lifetime *vs* m







2. The stars emitting the most energy are

Circle one: blue stars yellow stars red stars not-related to color

3. The stars emitting the most energy are

Circle one: high mass stars medium mass stars low mass stars

4. The stars with the longest lifetimes are the

Circle one: high mass stars medium mass stars low mass stars

5. The stars with the longest lifetimes are the

Circle one: blue stars yellow stars red stars not-related to color

6. A star that has ten times more mass than another star mass lives

Circle one: 10x longer about the same $^1/_{10}$ as long much less than $^1/_{10}$ as long

7. In general, the more massive stars emit

Circle one: less energy more energy energy amounts unrelated to mass

8. In general, the more massive stars have

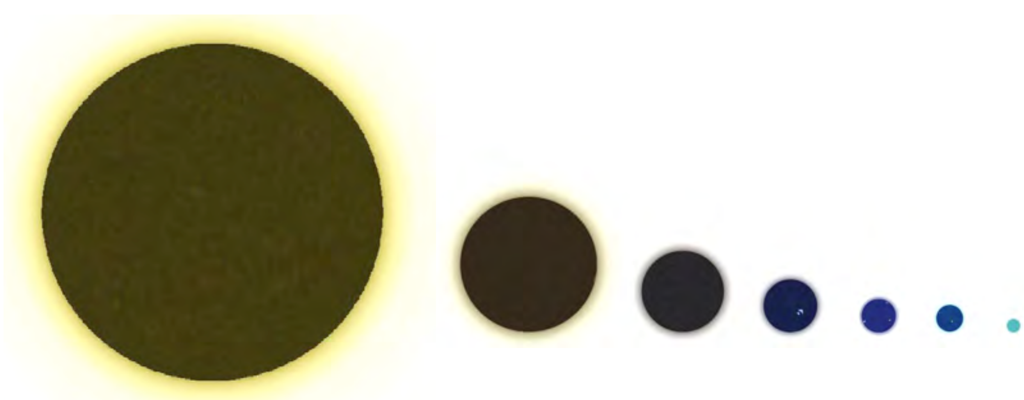
Circle one: shorter lifespans longer lifespans lifespans unrelated to mass

9. In general, the more massive stars are

Circle one: higher temperature lower temperature temperature independent

10. In general, stars that emit more blue light than other stars are

Circle one: more massive less massive found in a variety of masses



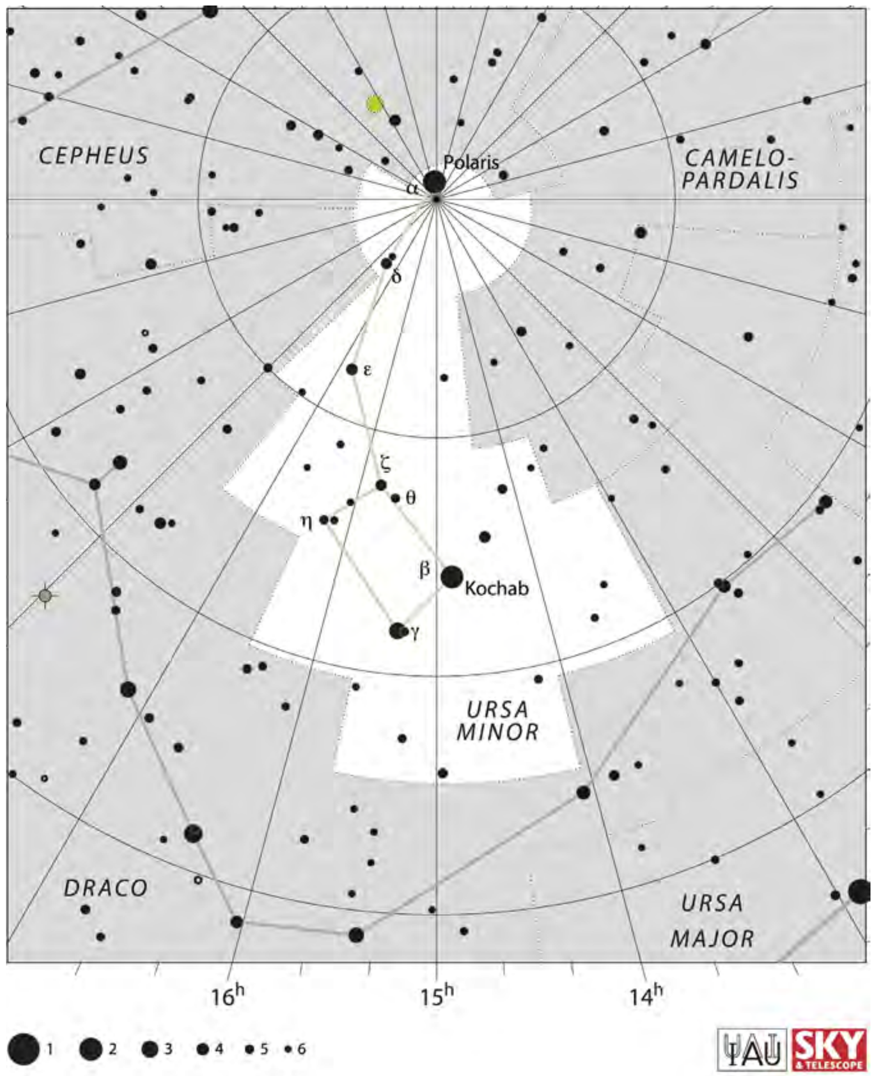
Adapted from https://commons.wikimedia.org/wiki/File:Dwarf_Stars.png |

Magnitude Scales 39

There are both bright stars and dim stars scattered across the night sky. Astronomers use a ranking system to describe the brightness of stars, much like sports teams might be ranked by how many wins they have.

The first group of brightest stars are ranked as #1, the next as #2, then #3, and so on until you get to magnitude #6—the dimmest stars you can see without a telescope.

Astronomers represent how bright a star appears—apparent visual magnitude—on a map using circles of different sizes. This illustration does ***NOT*** relate to how large or how close the stars are.



1. How many magnitude ONE stars are in the constellation of *Ursa Minor* where we find the 'Little Dipper'?

Circle one: zero one two three more than three

2. How many magnitude TWO stars are in the constellation of *Ursa Minor*?

Circle one: zero one two three more than three

3. How many magnitude FOUR stars are in the constellation of *Ursa Minor*?

Circle one: zero one two three more than three

4. Looking at the star map, what inference can you make about the number of stars at different brightnesses?

Circle one: There are more apparently bright stars than dim stars.

There are about an equal number of bright star and dim stars.

There are many more dim stars than bright stars.

Another way to think of the apparent visual magnitude system is to imagine sitting outside as the Sun is setting and watching the stars slowly start to appear in the darkening sky. The first group of stars appearing are the magnitude-1 stars. The next group of stars are magntitude-2, and so on.

Apparent Visual Magnitude	Approximate Number of Stars	Common Examples
1	20	Betelgeuse
2	50	Polaris
3	200	Algenubi
4	500	*So dim, rarely named*
5	1500	
6	7000	

5. If there is a bright moon or you live close to glaring city lights, you might not see any stars dimmer than magnitude-3. How many visible stars are you missing?

6. Most objects in the sky are so dim, you can't see them unless you have a telescope to help you gather the very little light being emitted and focus it so you can observe it. Using this system, what would the apparent visual magnitude numbers be like for those objects (*e.g., Pluto*)?

Circle one: negative numbers fractional or decimal numbers large numbers

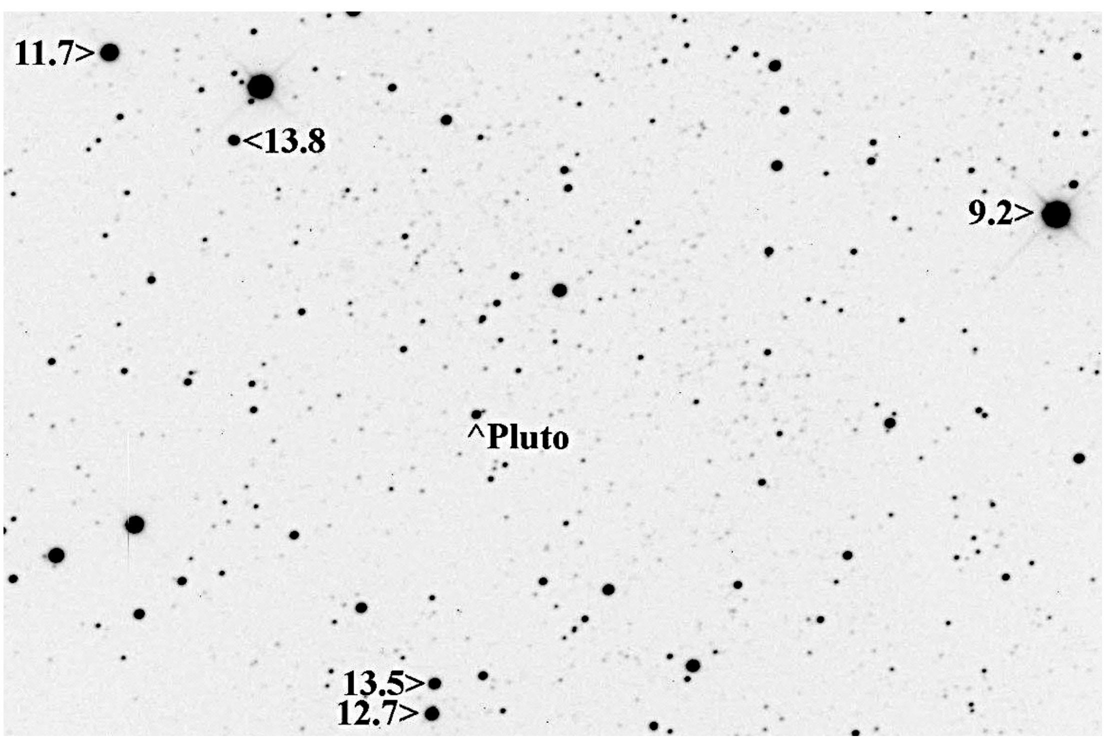
7. Based on the generalization you created earlier, how many stars across the sky might there be that are too dim to be seen without using a telescope?

Circle one: hundreds thousands millions or more

8. Some objects in the sky are much brighter than the stars, like the planet Venus. Using this system, what would the apparent visual magnitude numbers be like for those objects (*e.g., Moon*)?

Circle one: negative numbers fractional or decimal numbers large numbers

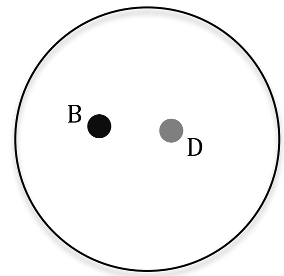
9. Use the nearby stars of known magnitudes to estimate the apparent visual magnitude of Pluto to at least one decimal place.



Credit: Kevin Heider, CC BY-SA (phys.org/news/2015-07-plutothe-planet.html)

Brightness and Distance

Starlight can be described in at least two ways. One is how bright it looks when you go outside and look up into the sky—**brightness** is sometimes called *apparent magnitude.* Another way is how much energy it is emitting—**luminosity**, sometimes called *absolute magnitude*—and is independent of how far away you are from the Star.



1. Imagine you are looking at two unknown stars, one bright and one dim. Based on how they look through the telescope, which one is closer?

Circle one: Brighter one Dimmer one Can't tell

2. If you knew by looking at the details of their spectra that the two stars were identical twins in size and total energy output (*luminosity and absolute magnitude*), which one is closer?

Circle one: Brighter one Dimmer one Can't tell

3. The apparent brightness of glowing objects depends on distance following the $^1/_{d^2}$ rule. If the bright star B is 5 times closer to us than identical star D, how much brighter does it look?

Circle one: 5x brighter 10x brighter 25x brighter

4. If instead, bright star B appears to be only 4 times brighter than its identical twin star D, how much closer is B to us?

Circle one: ½ as close ¼ as close 2x closer 4x closer 16x closer

5. If instead these two stars were at the same distance from us, how would they appear in the telescope?

Circle one: B would appear brighter D would appear brighter B & D would be same

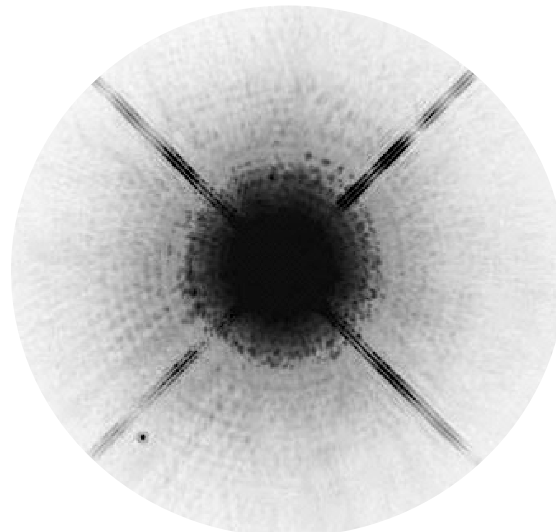
6. Imagine Earth between two identical stars. How many times brighter is the nearby star?

Circle one: 3x 6x 9x 10x 30x 90x 100x

The Hubble Space Telescope image at right shows Sirius, the brightest star in the night sky, and its tiny companion, Sirius-*B* (in the lower left hand corner). The two stars are orbiting very close to one another. (*The spikes are caused by the telescope's imaging system.*)

Sirius is 8.6 light-years away from Earth and shines about 10,000 x brighter than Sirius-*B*.

7. How far away is the much dimmer Sirius-*B*?



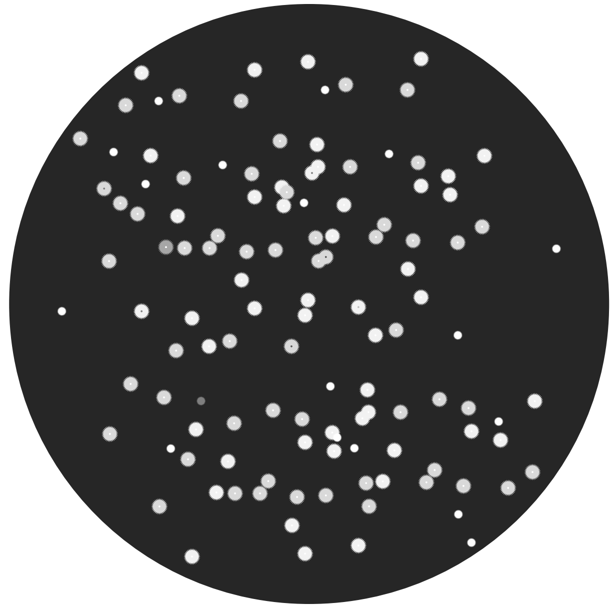
Credit: NASA, ESA, H. Bond (STScI) & M. Barstow (Univ. of Leicester)
http://www.spacetelescope.org/images/html/heic0516a.html

8. How many times farther away from Sirius would you need to travel for Sirius to appear as bright as Sirius-*B* does now?

Circle one: 8.6x 74x 10,000x 100,000x 100,000,000x

9. How long would it take light to travel that far?

Stars form from interstellar clouds of dust and gas. The figure at right shows a cluster of hundreds of stars as seen through a telescope.



1. Sketch how a large, butterfly-shaped dark nebula existing between Earth and the stars shown at right would change the figure.

2. The size of clouds like the one you've drawn are similar in size to a:

Circle one:

Large-city

Planet

Sun-like star

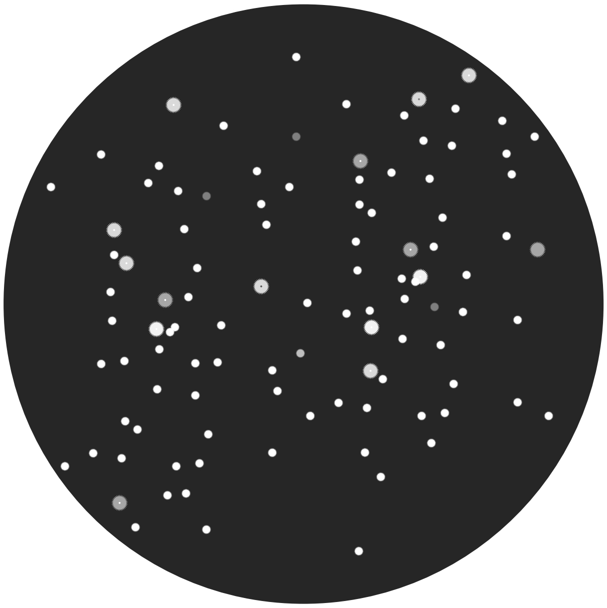
Solar System

A volume many light-years across

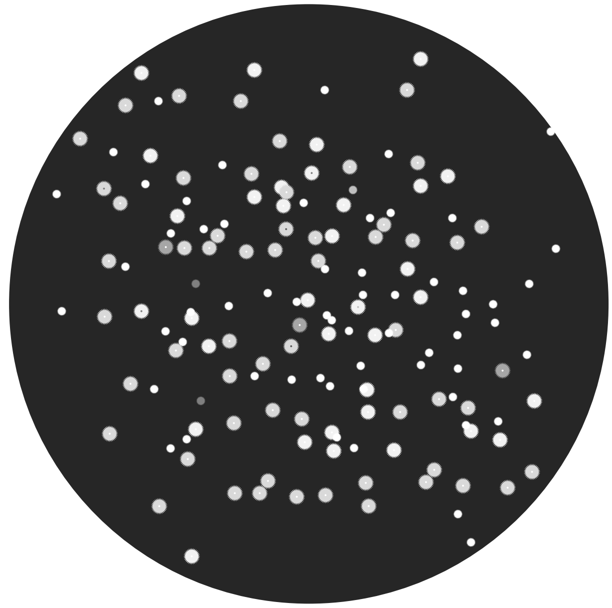
3. About how many new stars will form out of the cloud you drew?

Circle one: one several tens hundreds or more

Below are two stars clusters. Each cluster is about the same distance from Earth.



Gardenia Star Cluster



Plumeria Star Cluster

4. Which star cluster has more bright stars?

Circle one: Gardenia Star Cluster   Plumeria Star Cluster

5. Stars that emit the most energy have the shortest lifespans and disappear from view quickly. Which star cluster has already lost its bright stars?

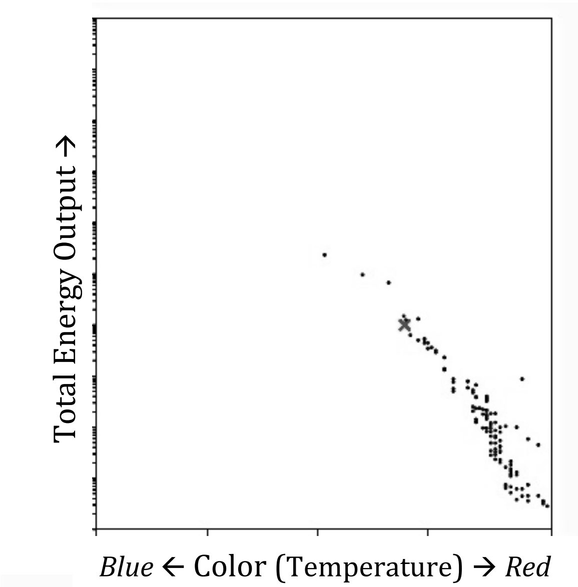
Circle one: Gardenia Star Cluster   Plumeria Star Cluster

6. Which star cluster is probably older?

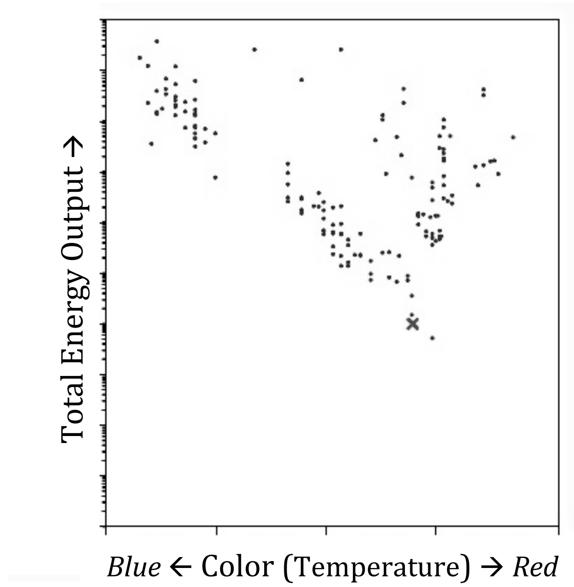
Circle one: Gardenia Star Cluster   Plumeria Star Cluster

7. Explain your reasoning behind your answer to which is probably older.

As we look across the many stars in the sky, we can begin to classify them into various categories. Two of the most fruitful are total energy output (*either luminosity or absolute magnitude*) and color (*temperature*). The graphs shown below are sometimes called *color-magnitude diagrams* instead of HR diagrams.



100 Stars NEAREST to Earth



100 Stars BRIGHTEST in Sky

1. What color are most of the nearby stars in our own stellar neighborhood?

Circle one: red yellow-white blue-white all colors

2. What relative temperature are most of the nearby stars in our own stellar neighborhood?

Circle one: hot medium cool all temperatures

3. What colors are most of the bright stars we see from Earth?

Circle one: red yellow-white blue-white all colors

4. What relative temperatures are most of the bright stars we see from Earth?

Circle one: hot medium cool all temperatures

5. In general, most of the stars in our galaxy are what relative temperature?

Circle one: hot medium cool all temperatures

6. Our Sun appears in the middle of each diagram marked with an "x". What is its color?

Circle one: red yellow-white blue-white all colors

7. Our Sun appears in the middle of each diagram. What is its relative temperature?

Circle one: hot medium cool all temperatures

8. Compared to the nearby stars in our local stellar neighborhood, the temperature of our Sun is relatively

Circle one: hot average cool

8. Compared to the nearby stars in our local stellar neighborhood, the energy output of our Sun is relatively

Circle one: high average low

10. Compared to most of the bright stars we see in the night sky, our Sun's energy output is relatively

Circle one: high average low

The graph below show the color (temperature) and absolute magnitude (luminosity) for several thousand stars in our galaxy.

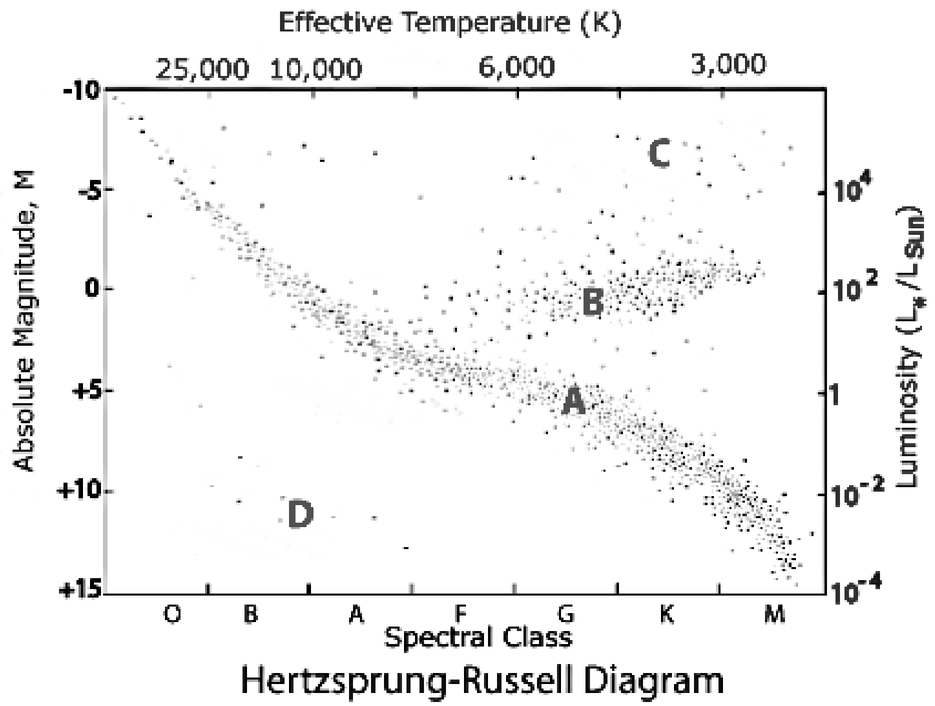


Image adapted from CSIRO, http://www.atnf.csiro.au/outreach/education/senior/cosmicengine/stars_hrdiagram.html

1. How are stars distributed across all possible color (*temperatures*) and magnitude (*luminosity*) combinations?

Circle one: equally distributed grouped

2. What are the characteristics of stars around region D?

Circle one: hot & low luminosity cool & low luminosity giant

3. What are the characteristics of stars around region C?

Circle one: hot & high luminosity cool & high luminosity giant

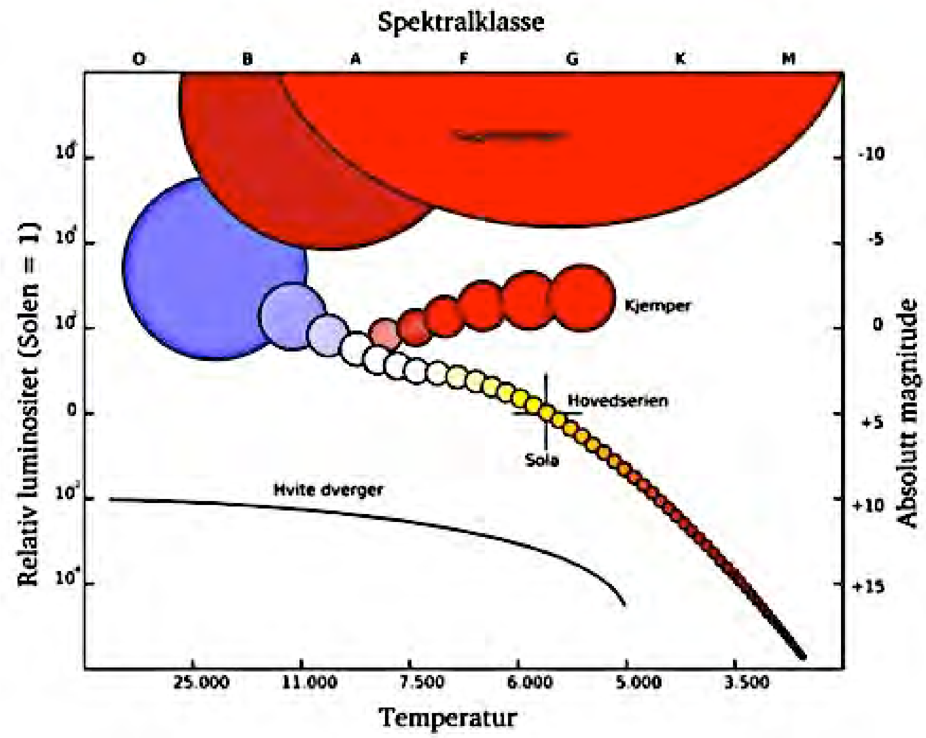
4. Which Spectral Class represents the lowest temperature stars?

Circle one: O A G M

5. Which Spectral Class represents the majority of stars?

Circle one: O A G M

6. Label the diagram with names for the four lettered regions.



https://astrofysikk.wikispaces.com/HR-diagram Creative Commons Attribution Share-Alike 3.0 License

7. What are the relative temperatures of the dimmest stars?
Circle one: low medium high a wide range of temperatures

8. What are the relative sizes of the dimmest stars?
Circle one: small medium large a wide range of diameters

9. The vast majority of stars are relatively
Circle one: hot small

10. Two astronomers are talking about sizes and temperatures of stars.

Astronomer Pat: There is a straightforward relationship when it comes to stars: Small stars are cool, and big stars are hot.

Astronomer Chris: That is true for stars stably fusing hydrogen into helium; but some giant stars are cool, but are so big that they emit a tremendous amount of light.

Which astronomer do you agree with and why? *Explain*.

Stars shine because lighter atoms are being fused into heavier atoms, releasing energy in the process. One of the most common fusion processes inside stars is the *Proton-Proton Chain*.

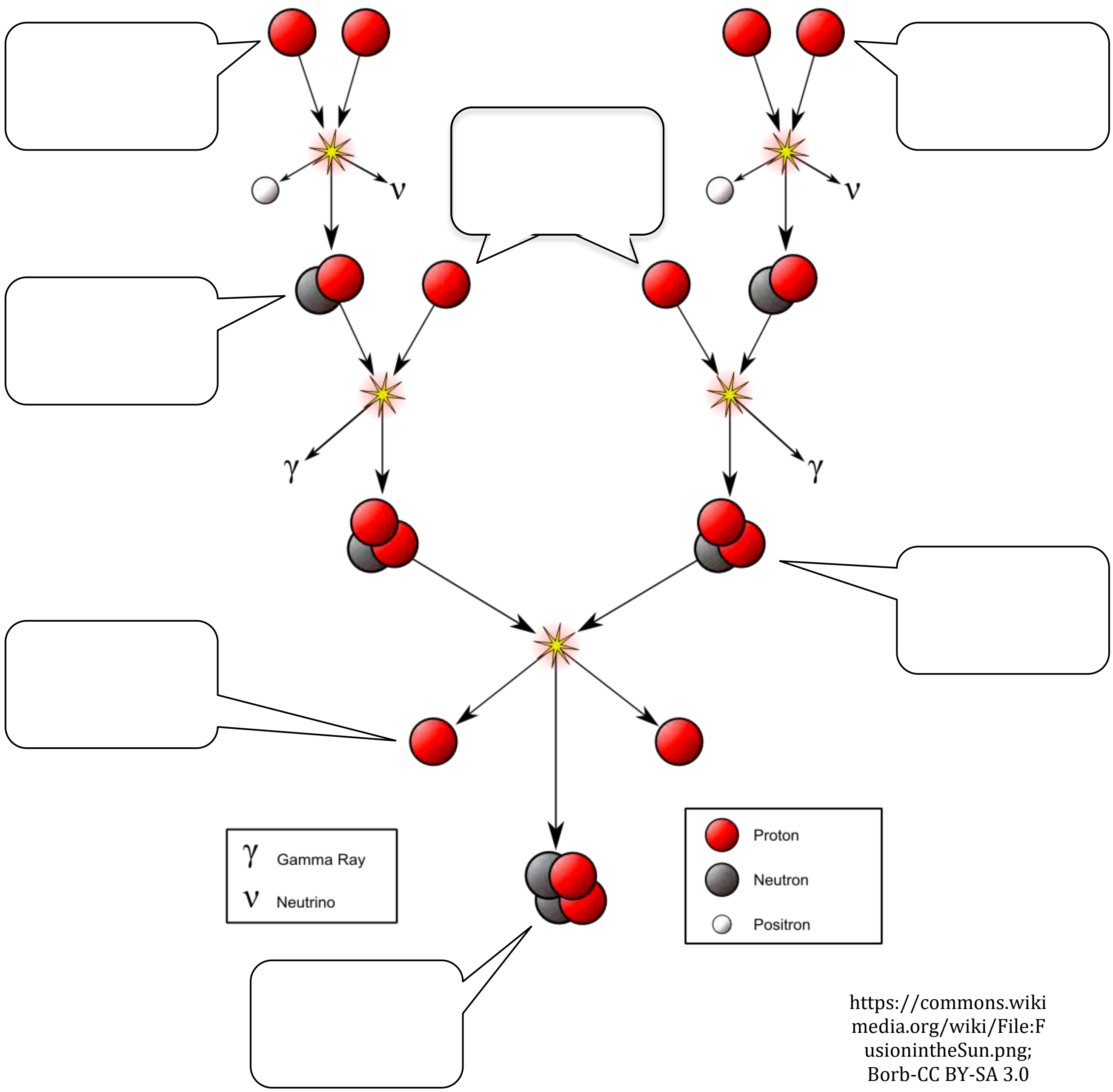
1. In the spaces below, label each object as Hydrogen, ^{1}H; Deuterium, ^{2}H; Helium-3, ^{3}He; and Helium, ^{4}He.

2. In which place is energy emitted that eventually causes a star to visibly shine?

Circle one: neutrino release gamma ray release the splitting of atoms

3. Which equation describes what is going on here?

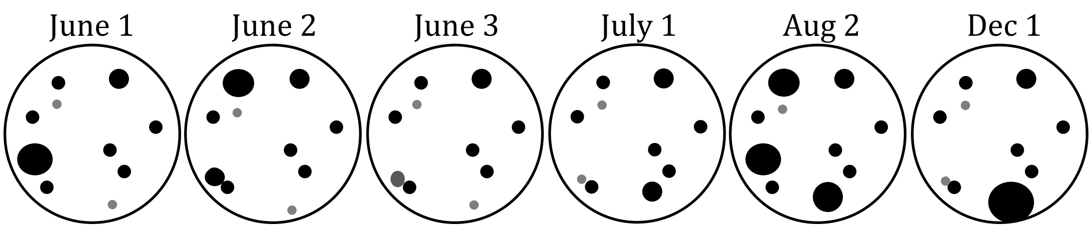
Circle one: $E=h\nu$ $E=mc^2$ $E=mgh$ $E=Gm_1m_2/d^2$



https://commons.wikimedia.org/wiki/File:FusionintheSun.png; Borb-CC BY-SA 3.0

As you look up into the night sky, you probably notice that some stars are bright whereas other stars are dim. For the most part, stars are always seem to be the same brightness. There are some stars, however, that do vary in brightness.

One category of variable stars are those unstable stars that actually change in size. They are brightest when they are swollen up to be large in size: they are dimmest when they shrink to be small in size. Consider these observations of stars through a telescope.



1. Short-period RR Lyrae variables have a bright-dim-bright period of about 1 day. *Circle the short period RR Lyrae variable in the images above and label it on the Dec 1 observation.*

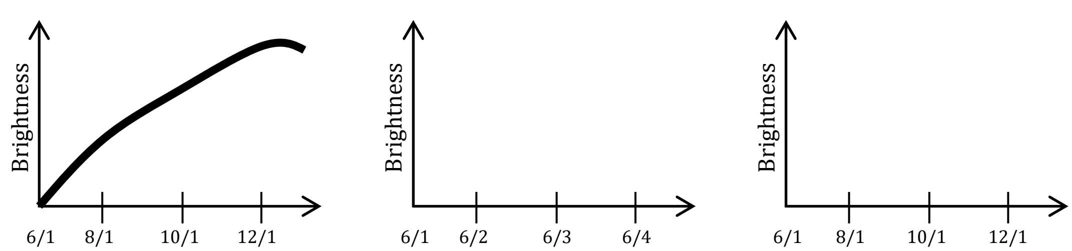
2. Long-period Mira variables have bright-dim-bright periods ranging from 80 to 1,000 days. *Circle the long period Mira variable in the images above and label it on the Dec. 1 observation*

3. Medium-length Cepheid variables bright-dim-bright periods averaging about 60 days. *Circle the medium period Cepheid variable in the images above and label it.*

Stars are so far away, that they are just tiny pinpoints of light, immeasurably small even with most telescopes. However, when you take a picture of the stars, the brightest ones take up more space and smear out in the picture.

When you analyze these pictures, your brain wants to imagine that the brightest stars are always physically bigger because they take up more space on the picture. Brighter stars are sometimes actually bigger, but not always; don't confuse the size of the star's blob on the picture and it's actual size.

4. One way we analyze variable stars is to create a graph of how they change their brightness over time. The first figure below shows a "light curve" for the Mira variable above. *Sketch in the two "light curves" for the RR Lyrae and Cepheid variables from above.*



5. Two astronomers are discussing the nature of variable stars.

> *Astronomer Pat*: It seems to me that stars that change brightness very quickly must not be changing their size very much, because big changes in brightness would require big changes in size, which probably takes a star a long time.
>
> *Astronomer Chris*: I disagree. The length of a bright-dim-bright cycle depends on how far away the star is from Earth and how long it takes light to travel from the star to Earth.

Which astronomer do you agree with and why? *Explain*.

Star Lifetimes 46

Example Stars	Luminosity, $L_{\odot}$ (in Sun's)	Color	Mass, $M_{\odot}$ (in Sun's)	Radius, $R_{\odot}$ (in Sun's)	Lifetime (Est. Years)
Proxima Centauri	0.002 (0.2%)	Dark Red	0.12 (12%)	0.14 (14%)	100's of billions
Epsilon Indi	.22 (22%)	Orange	.76 (76%)	.73 (73%)	30 billion
Sun (Sol)	1.0	Yellow	1.0	1.0	10 billion
Gamma Virgo	6 ½	Yellow-White	1 ½	1 ½	3 billion
Vega	40	White	2	2 ½	400 million
Tau Scorpius	18,000	White-ish Blue	15	10	30 million
Rigel	120,000	Blue-ish White	20	15	15 million
Zeta Pupis	750,000	Blue	50	25	3 million

** These numbers are rough estimates.*

1. The Sun has enough useable hydrogen fuel so that it can shine as it does now for of about 10 billion years. What about the lifetimes of stars that are about ¾ the Sun's radius?

Circle one: ¾ as long same lifespan ¾ longer 3x longer much longer

2. What are the lifetimes of stars 50% larger in mass than the Sun's 10 billion year lifespan?

Circle one: $^{1}/_{3}$ as long 50% as long 50% longer 2x longer much longer

3. What are the lifetimes of stars two times (2x) more massive than the Sun?

Circle one: 40% as long ½ as long 50% longer 2x longer much longer

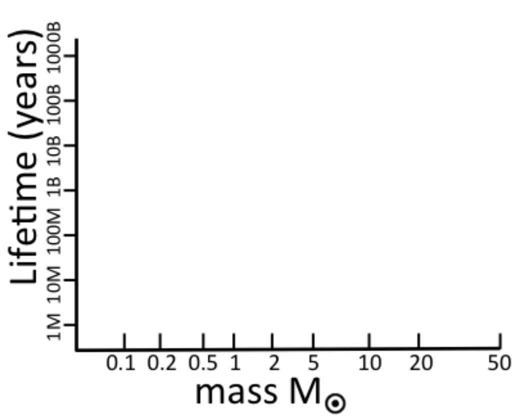
4. What are the lifetimes are stars twenty times (20x) more massive than the Sun?

Circle one: $^{1}/_{20}$ as long billions of years millions of years

5. What are the lifetimes of most of the stars in our galaxy?

Circle one: millions of years billions of years 100s of billions of years

6. Draw a graph of star lifetimes versus star masses on the figure below



7. On the diagram below, draw and label an arrow showing main sequence stars with the longest hydrogen-fusing lifetimes.

8. On the diagram below, draw and label an arrow showing main sequence stars with the shortest hydrogen-fusing lifetimes.

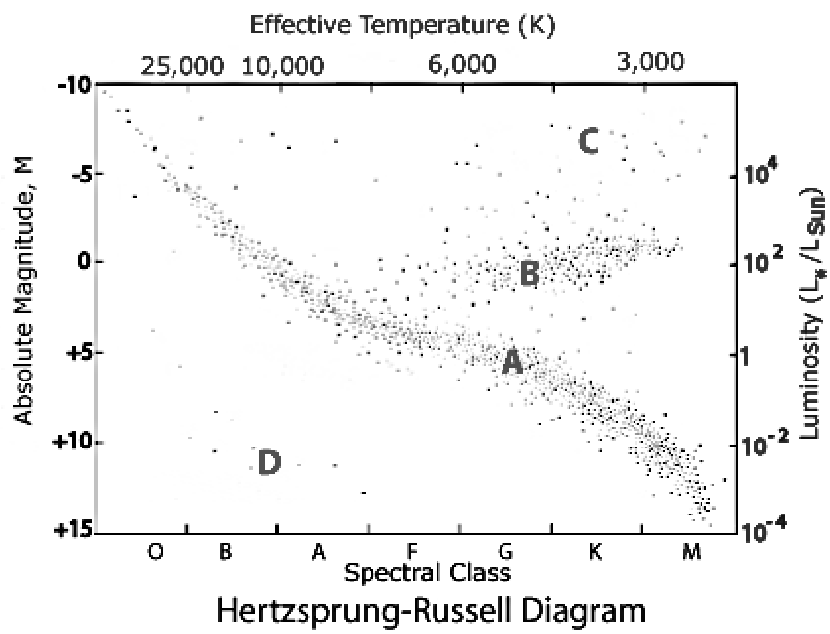
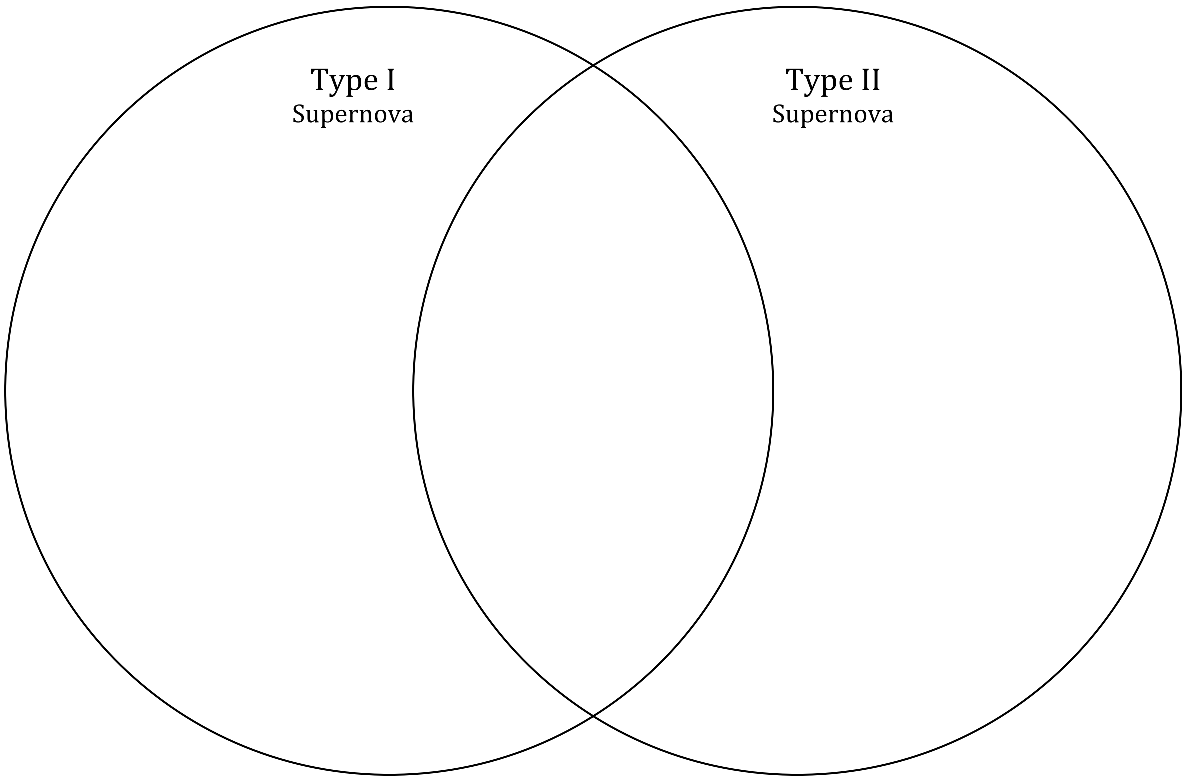


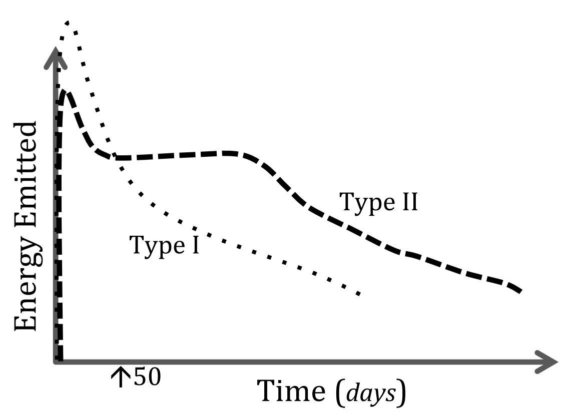
Image adapted from CSIRO, http://www.atnf.csiro.au/outreach/education/senior/cosmicengine/stars_hrdiagram.html

Type I and Type II Supernova

1. Complete the Venn Diagram with the supernova characteristics listed below:



Characteristics	Examples
☐ Largest peak luminosity	☐ Close binary system
☐ Visible longest	☐ Crab Nebula
☐ Created from two stars	☐ SN 1987A
☐ Created from a single star	☐ Zeta Pupis, a $50M_\odot$ star
☐ Leave no remnant	
☐ Creates nebula	
☐ Standard candle	
☐ Visible in distant galaxies	
☐ Occurs one time	
☐ Stimulates nearby star birth	



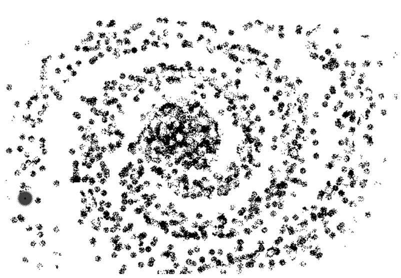
2. Two astronomers are talking about supernova types.

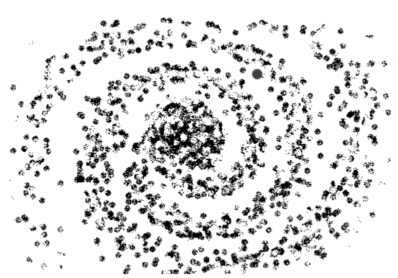
Astronomer Pat: I don't know why we talk about type I and type II when seems to me that a dim one should be a regular-nova, and a really bright one should be a super-nova.

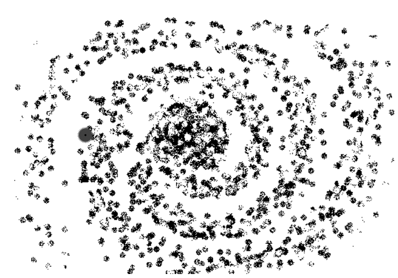
Astronomer Chris: That's easy. A nova is a completely different situation

Which astronomer do you agree with and why? *Explain*.

3. Circle the three supernovae in the images captured by a telescope in the panels below (*there is one in each image*).

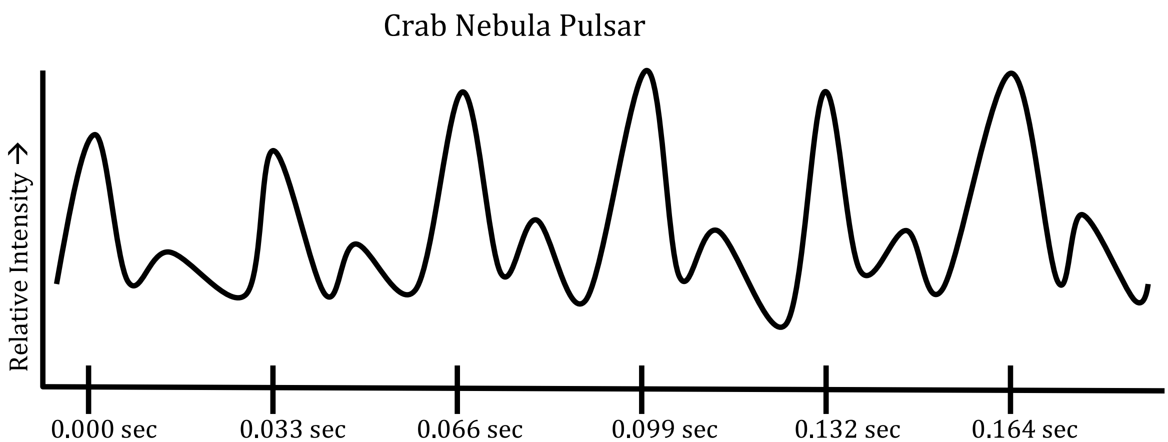






2005 2010 2015

A pulsar is a tiny, quickly spinning neutron star with a particular "hot spot" that emits a tremendous amount of energy. When observed from Earth, this appears to us as a quick "pulse" of light from an otherwise dim object, called a *pulsating radio star*—or pulsar for short.

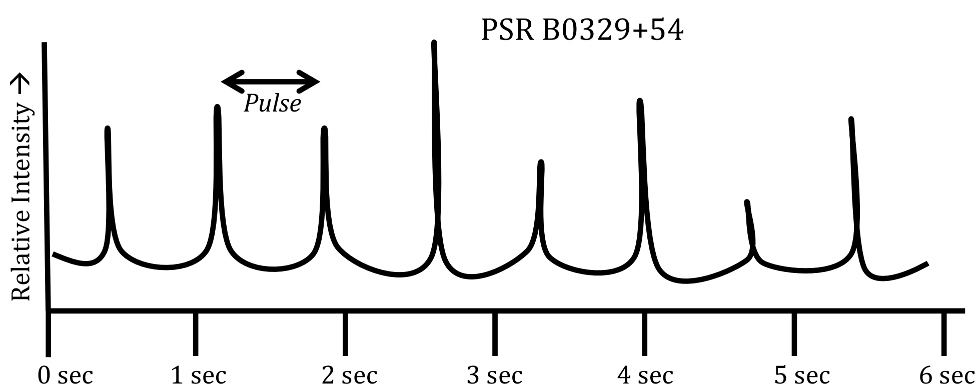


1. Using the above graph, determine the time period between pulses of light observed here on Earth for the Crab Nebula Pulsar.

2. This period you determined from the graph above is the

Circle one: time for pulsar to spin once number of times it spins per second

3. Using the graph below, determine the time period between several pulses of light and then average to determine the period for PSR B0329+54.



4. Over time, pulsars spin slower and slower as they age. Rank order the following pulsars by age based on their spin rate.

Youngest ← _________ _________ _________ _________ _________ _________ → Oldest

Pulsar	Formal Designation	Period	Number of Spins Every Second (*approx.*)
A	PSR B0329+54	0.714 sec	1 ½
B	PSR J2144-3933	8.51 sec	0.12
C	PSR J0058+4950	0.9960 sec	1
D	PSR J2111+2106	3.9538 sec	0.25
E	PSR J2030+3641	0.20012 sec	5
F	PSR B0531+21	0.0335 sec	30

*Many thanks to recycled pulsar specialist Jason Boyles for identifying these comparative pulsars

5. Two astronomers are arguing about neutron star observations.

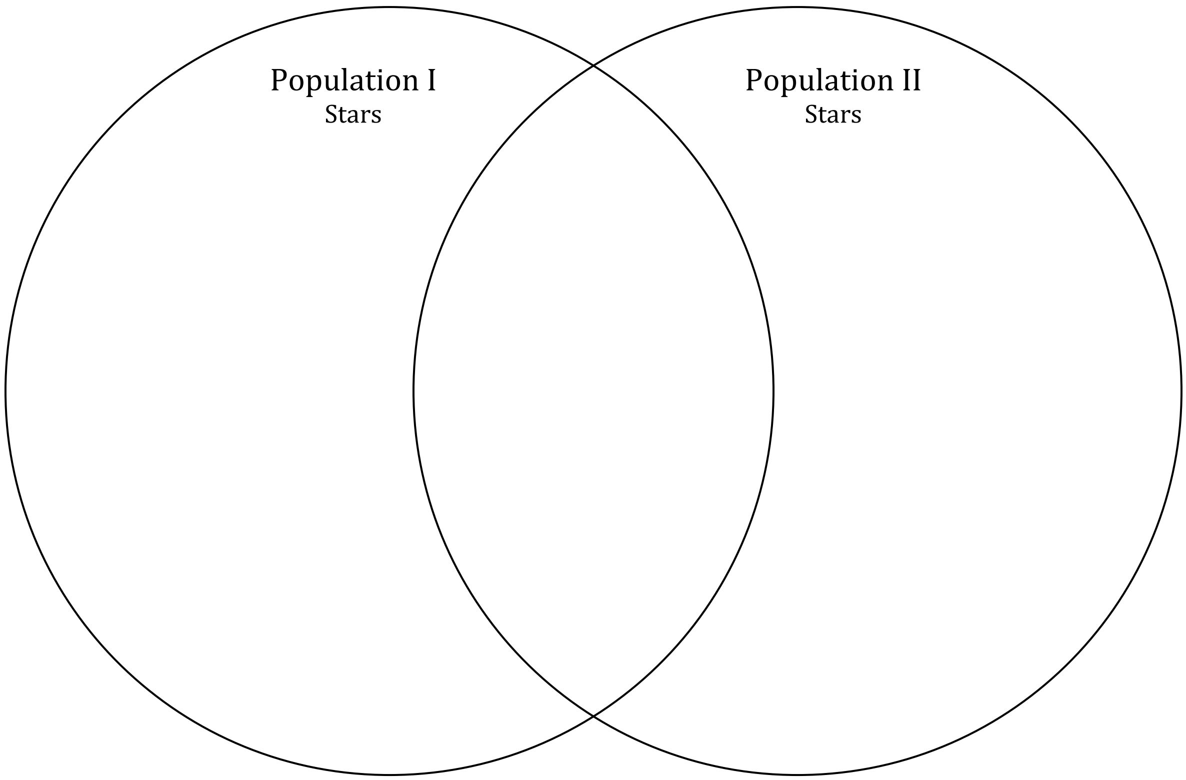
> *Astronomer Pat*: Any observed neutron star that lacks any pulsed emission is very old and is no longer spinning.
>
> *Astronomer Chris*: I disagree. It could be that spinning neutron star's "hot spot" does not intersect Earth and is emitting in some other direction.

With which astronomer do you agree and why? *Explain*.

Galaxies

There are many different—and equally valid—ways to categorize stars. One way is stars that are Sun-like, and those that are not: We unimaginatively call these **Population I** and **Population II** stars, respectively.

1. Complete the Venn diagram with the stellar population characteristics listed below:



Characteristics	Examples
☐ Metal-rich	☐ Sun
☐ Metal-poor	☐ Great Globular in Hercules, M13
☐ Found in the galactic halo	☐ Alpha Centauri
☐ Found in the galactic disk	☐ Mu Arae, a *nearby metal-rich star*
☐ Found in ultra-dense star clusters	
☐ Found in open, galactic clusters	
☐ Older	
☐ Younger	

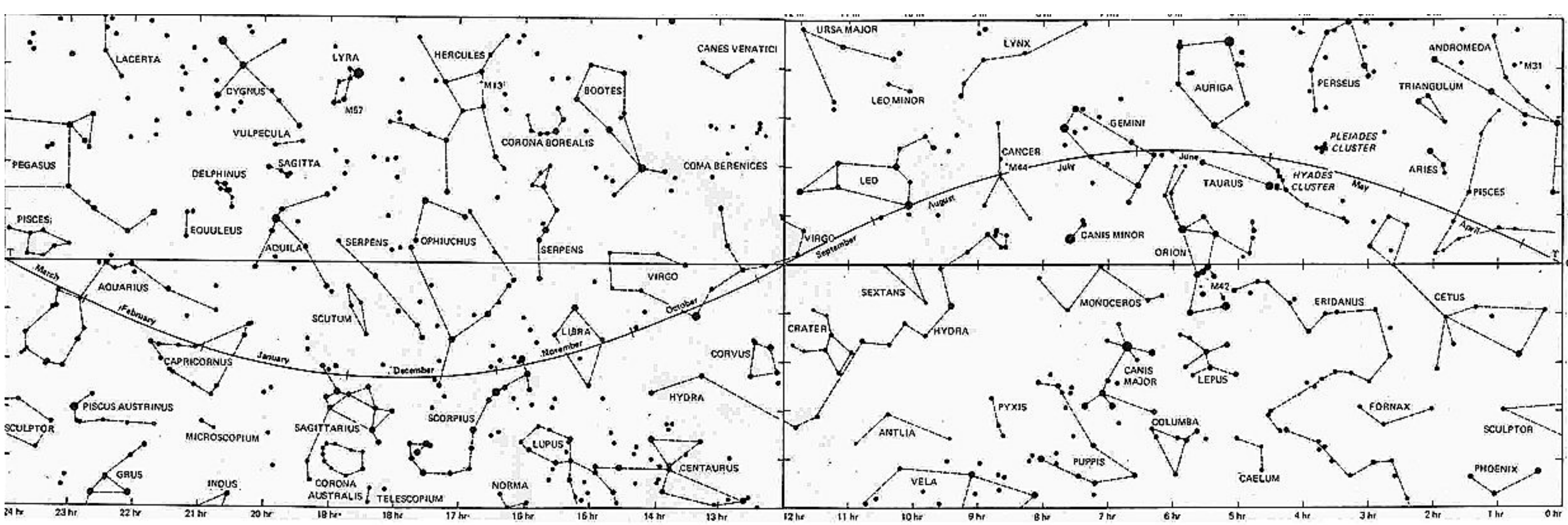
Perhaps Important Caveat: Stars that try defy this categorization scheme definitely exist. Some astronomers argue for a third population of supermassive but unmixed stars, temporarily called Population III stars. Other astronomers break Population I stars into early extreme and intermediate subcategories.

Below is a map of the entire sky: If you imagine the sky wrapped around Earth, this is what it looks like if you unwrap it and spread it out as a single map.

1. Mark the following objects on the map using large “x” marks of different colors or dramatically different shapes.

<u>Constellations Containing</u>

- ☐ Open Clusters: → Gemini, Aurigae, Scorpio, Sagittarius, Taurus, Coma Bernices, Canis Major, Perseus, Orion, and Lyra, marked with _______ symbol
- ☐ Active Star Forming Regions: → Orion, Taurus, Cancer, Ophiuchus, Serpens, and Sagittarius, marked with _______ symbol
- ☐ Dark Nebulae: → Ophiuchus, Orion, Cygnus, Sagittarius, Lupus, Vela, Aurigae, Cassiopeia, and Lacerta, marked with _______ symbol
- ☐ Supernova Remnants: → Taurus, Aquila, Vela, Cygnus, Centaurus, Lupus, and Ophiuchus, marked with _______ symbol
- ☐ Globular Clusters: → Centaurus, Indus, Aquarius, Hercules, Pegasus, and Capricorn, marked with _______ symbol



2. Are the open clusters randomly distributed across the sky, or do they fall along a curving line through the sky?

Circle one: Random Fall roughly along a curved line

3. Are the active star forming regions randomly distributed across the sky, or do they fall along a curving line?

Circle one: Random Fall roughly along a curved line

3. Are the supernova remnants randomly distributed across the sky, or do they fall along a curving line?

Circle one: Random Fall roughly along a curved line

4. Do the dark nebulae appear along roughly the same line as the supernova remnants, active star forming regions, and open clusters through the sky?

Circle one: Random Fall roughly along a curved line

5. Now, consider the globular clusters. Are the globular clusters evenly distributed across the sky?

Circle one: Evenly distributed same curved pattern as the other objects circular

6. Globular clusters are not always found in the disk of the galaxy; instead, they encircle the center of a galaxy. Draw a line connecting the constellations with globular clusters into a circle pattern to identify the direction of the galactic center.

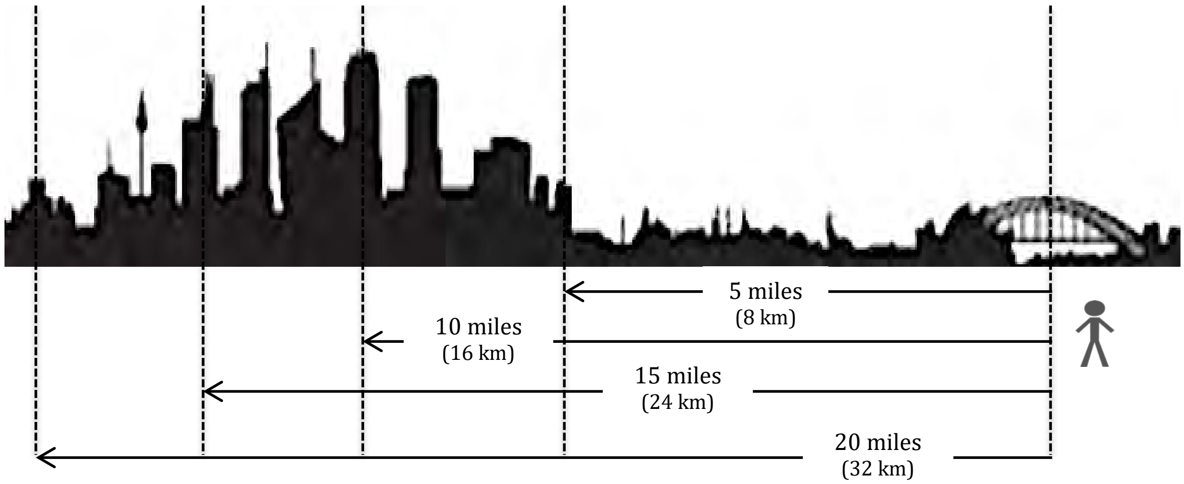
7. In which of the following constellations is our galactic center seemingly located?

Circle one: Hercules Sagittarius Orion

8. If the galactic center was in the direction of Gemini, how would the distribution of globular clusters look different?

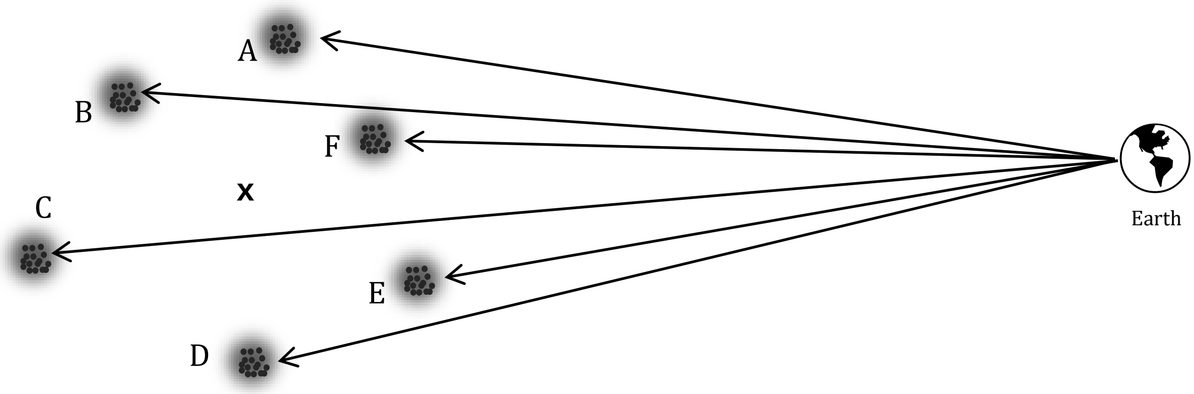
9. If Earth were located in the center of the galaxy, how would the distribution of globular clusters look different?

When looking at a city off in the distance, you can determine where location of city center by measuring the distances to identifiable buildings and finding the average distance.



1. How far away is the city center based on the four distance measurements to buildings in the city?

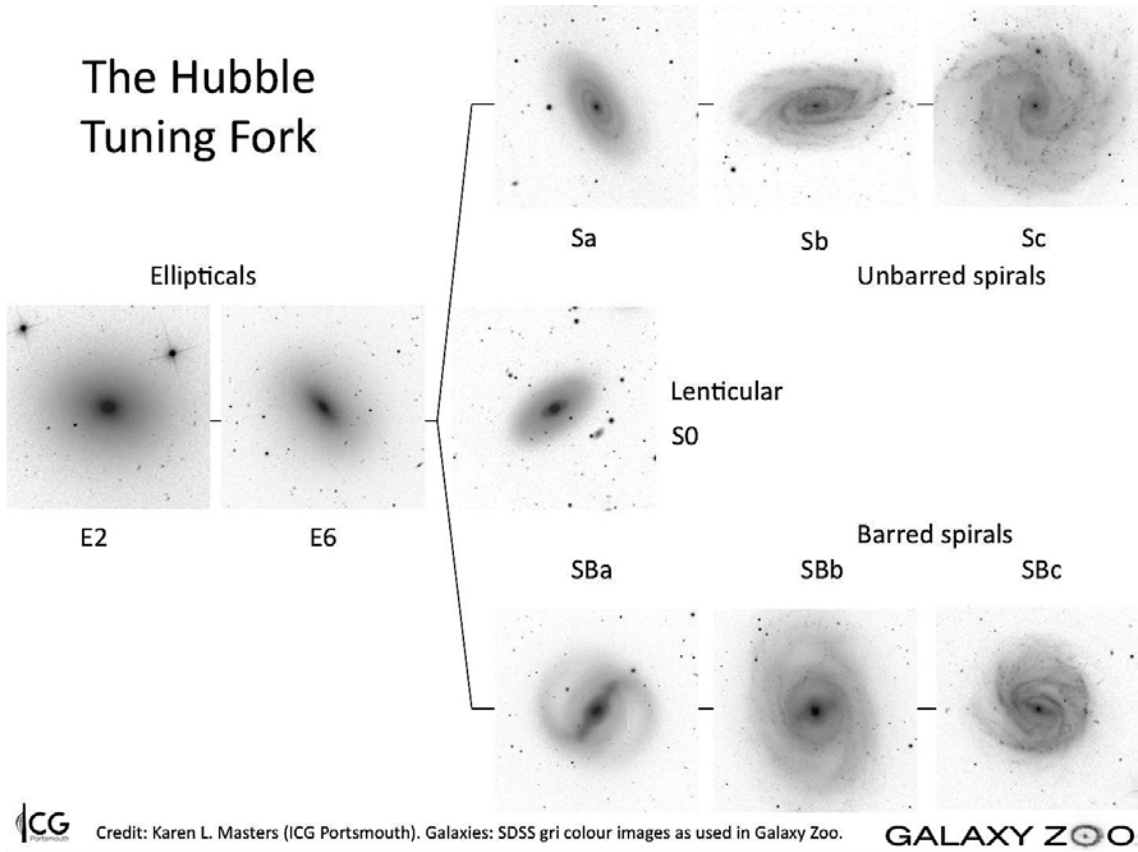
Finding distances to globular clusters surrounding the galactic center (x) depends on being able to find Cepheid variables within them. A Cepheid variable with a known brightness cycle indicates how far away it must be.



2. Complete the table below to determine the distance to the Galactic Center.

Globular Cluster	Est. Distance to Globular Cluster (*Light-Years*)
A	24,000
B	40,000
C	55,000
D	15,000
E	7,000
F	8,000
Average Distance to Center of Galaxy =	

Galaxies are gravitationally bound, isolated islands of hundreds of millions or billions of stars and interstellar dust. Galaxies don't come in every possible shape and size; instead, they can be categorized into particular groups using a variety of strategies. One of the most common classification scheme is known as the *Hubble Tuning Fork*.



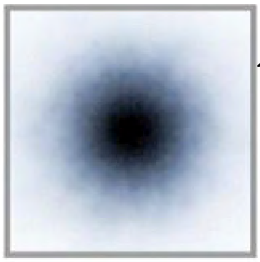
1. What characteristic makes an elliptical appear distinguishingly different a spiral?

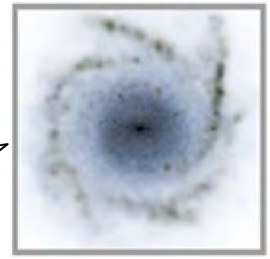
2. What characteristic makes a spiral appear distinguishingly different a barred spiral?

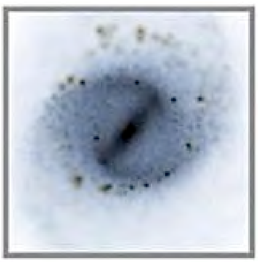
3. Elliptical galaxies are often given a number between E0 and E7 to describe their shape. In the spaces below, sketch an EO, and E4, and an E7.

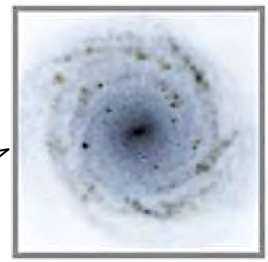
E0 Elliptical	E4 Elliptical	E7 Elliptical

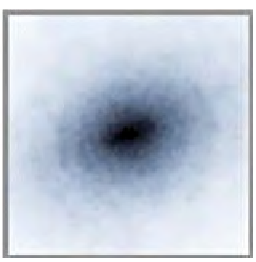
4. Classify the images of galaxies observed by the Sloan Digital Sky Survey using the *Hubble Tuning Fork* system.

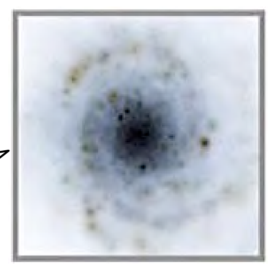


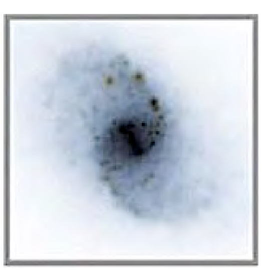


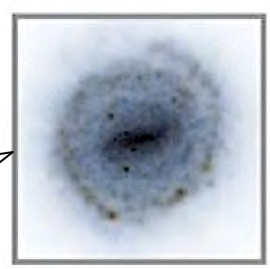






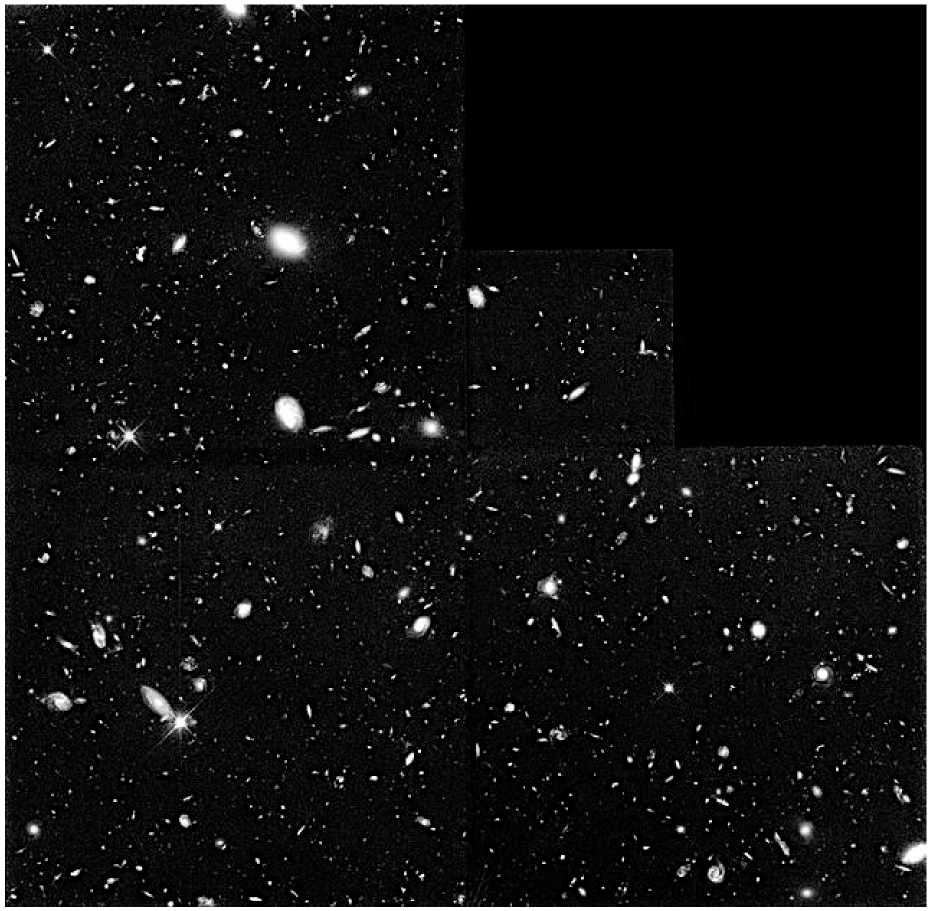




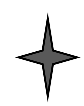


Hubble Deep Field

One of the most iconic pictures in astronomy is known as the Hubble Deep Field. Covering only a tiny amount of sky that was previously considered to be empty before being carefully imaged, astronomers can see that the Universe is has numerous galaxies of stars.



1. When imaged by the Hubble Space Telescope, nearby stars inside our own galaxy—called foreground stars—appear to have sharp points, as shown at right. How many stars can you find in this image?



Circle one: none 1 ≈5 ≈10 100s 1,000s millions

2. If we make the broad assumption that most galaxies in this image are about the same actual size, then are there more galaxies near our or more galaxies that are far away?

Circle one: most galaxies are nearby most galaxies are distant

3. When looking at the galaxies that are largest and easiest to see in this image, are galaxies seen more often spirals or more often ellipticals?

Circle one: most are spirals most are ellipticals

4. Two astronomers are arguing about the importance of the Hubble Deep Field image.

   Astronomer Pat: The Hubble Deep Field clearly shows that there are many more galaxies than we thought before.

   Astronomer Chris: I don't think so. We could have just gotten lucky and galaxies are particularly numerous in that particular direction.

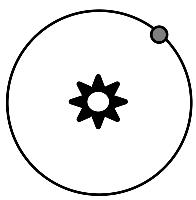
With which astronomer do you agree and why? *Explain*.

NOTE: Calculator questions marked with 🖩 symbol are optional.

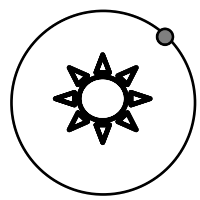
As we look across the Universe, we expect gravity to force objects to move in ways predicted by Kepler. Newton's ideas about gravity mean that the most massive objects have the most gravitational attraction and force things to move most quickly, according to $M \times p^2 = a^3$

1. According to the *Law of Universal Gravitation*, the time it takes a planet to orbit a star depends mostly on how massive the central star is. Figure 1 represents Earth orbiting the Sun (Sol), taking one year. If Earth, instead, orbited a star that was four times (4x) more massive than our Sun, but at the same distance, how would its orbital speed be different?

Circle one: Orbit slower No difference Orbit faster



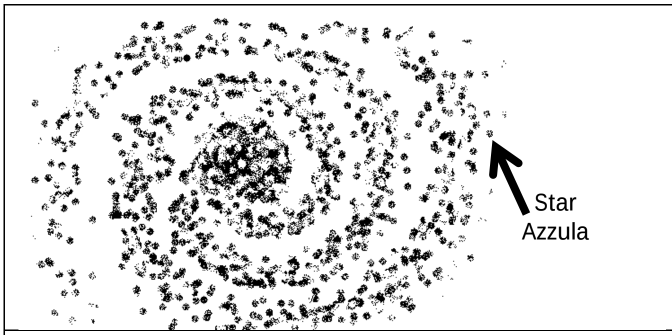
Planetary System #1: *Sol*
$Mass_{STAR} = 1_{Sun}$
$mass_{planet}$ = tiny
a_{Orbit} = 1 AUnit

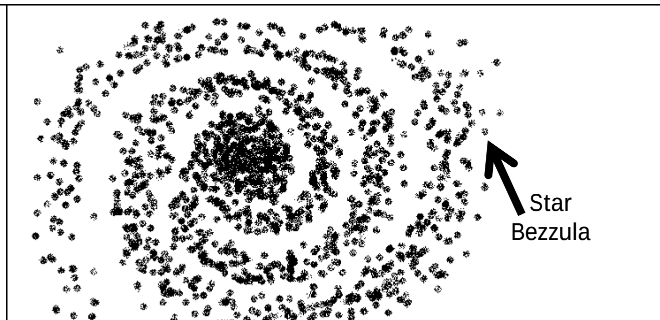


Planetary System #2: *Polaris*
$Mass_{STAR} = 4_{Sun}$
$mass_{planet}$ = tiny
a_{Orbit} = 1 AUnit

2. 🖩 If orbital period $P = \sqrt{(a_{distance}^3 \div Mass)}$, then calculate how long does it take to orbit the $4M_{Sun}$ star. $P = \sqrt{(a_{distance}^3 \div Mass)} = \sqrt{(1_{AU}^3 \div 4_{Sun})} = \sqrt{(0.25)}$ = ________ year

3. Figure 2 below illustrates two spinning galaxies, one made up of 100 billion stars, and the other with 1,000 billion stars. If the star Azzula orbits its galaxy at the same distance as star Bezzula, but its galaxy is (*10x*) more massive than our Sun, but at the same distance, how would its orbital speed be different? (*circle one*)
Orbit slower No difference Orbit faster





Mass: 100 billion star galaxy, Period: star Azzula orbits every 400 million years	1,000 billion star galaxy Period: star Bezzula orbits every ____ Myr

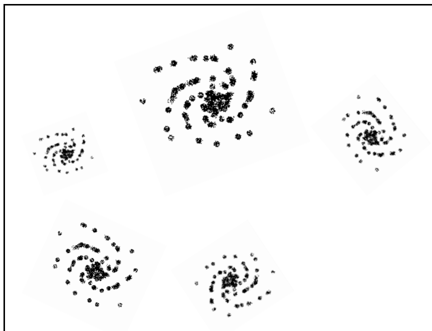
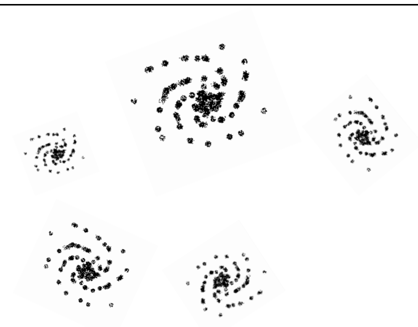
4. 🖩 If orbital period $P = \sqrt{(a_{distance}^3 \div Mass)}$, then calculate how long does it take to orbit the $10M_{Galaxy}$ galaxy.

5. Imagine you were observing a tiny, spinning galaxy, which you carefully count and find it has 1,000,000 stars. When you measure the speed at which a star at the edge is orbiting, you find it takes only about half as long to go around as you expect. Two astronomers are arguing about why this might be.

> *Astronomer Pat*: I think that not all the stars were counted. I mean, with a million stars, one could easily lose count.
>
> *Astronomer Chris*: I disagree, the stars' orbital speeds are directly connected to how much material is present, then there must be some matter that isn't shinning and can't be seen.

With which astronomer do you agree with and why? *Explain*.

6. The figure below shows two galaxy clusters, orbiting around one another. If the two sets of stars have the same separation distance and seem to have the same number of stars, which cluster has more unseen matter? *Circle one*: Cluster #1 Cluster #2

	
Galaxy Cluster #1: 900 million year period	Galaxy Cluster #2: 300 million year orbital period

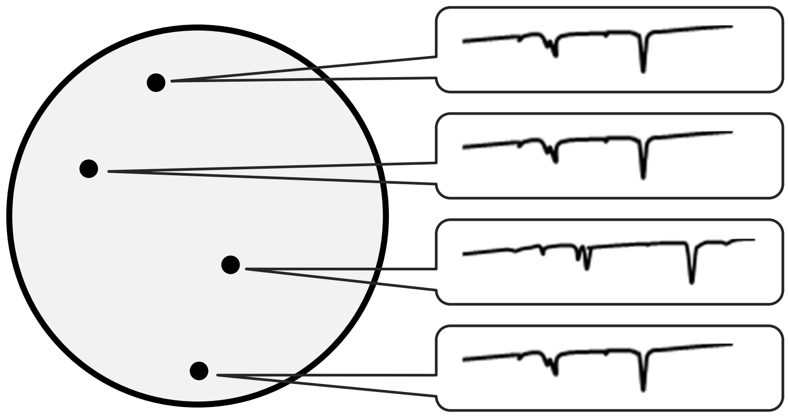
7. If $Mass_{Total} = a^3_{distance} \div P^2_{OrbitalPeriod}$, then calculate how many times more mass does one cluster have than the other.

> *If your brain likes to think about more massive things causing bigger gravitational effects, then you should congratulate your brain for thinking correctly in this case! When things in outer space are moving more rapidly than we expect, we infer the existence of some mysterious, seemingly invisible, non-glowing material that we call dark matter.*

8. Both our planets Jupiter and Saturn have moons orbiting them at about the same distance, but Jupiter's moons orbit faster than Saturn's moons. What can you infer about the difference between Jupiter and Saturn? *Explain your reasoning.*

Structure and Evolution of the Universe

Stars are so far away that most stars appear as infinitely small pin-points of light.
Even with the world's largest telescopes. One of the most important tools astronomers have to distinguish one star from another is to look at its "**spectrum**" – *a graph showing the intensity of light emitted at each wavelength*. Let's look at some dim stars and their spectra

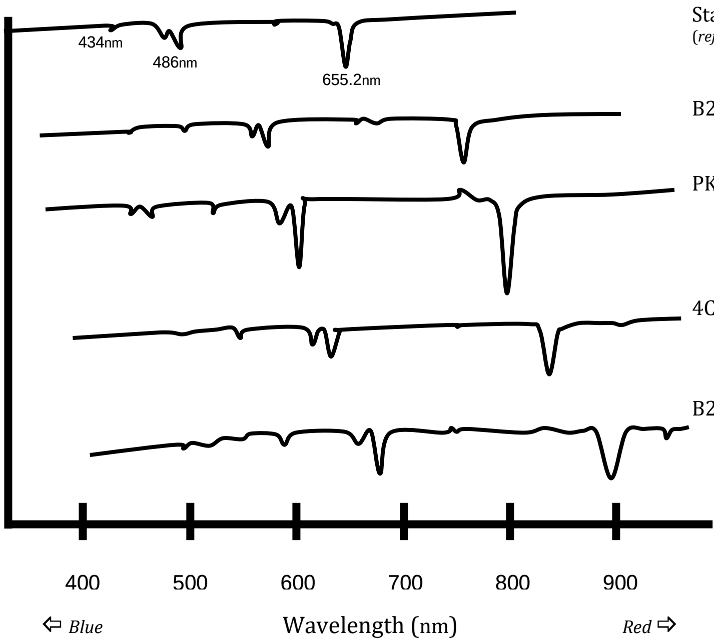


1. The figure above shows four dim stars as seen through a large telescope. How does the brightness or shape of the stars appear different from one another?

2. The stars spectra are also illustrated, and one is definitely different. Because it looks like a star, but it has a very different spectrum, it is called a **Quasi-Stellar Object**, or **QUASAR**. Precisely how is its spectrum different (*NOTE: On most spectra, shorter wavelengths are on the left and longer wavelengths are on the right)*

3. Using what you know about Edwin Hubble's observations about galaxies, what does a large red-shift imply about a galaxy's motion.

4. What is the Hubble relationship between a galaxy's recessional velocity and it's distance?



5. The first spectra on the top of the illustration above shows the spectrum of glowing hydrogen gas created in a non-moving laboratory on Earth. What is the wavelength for its largest, most obvious spectral feature?

6. The remaining four spectra are from Quasars. Complete the table to show the shifted wavelengths for this same, obvious spectral feature?

QUASAR	Feature Wavelength (nm)	🖩 *OPTIONAL* *Percent Difference from stationary* **Z**=(observed – stationary) ÷ (stationary)
B2 1128+31		
PKS 1217+02		
4C 73.18		
B2 1208+32		

7. The more the wavelength is shifted, the farther away the object is. 4C 73.18 is about 5 billion light-years away. How long did it take the light from 4c 73.18 to get to Earth?

8. What can you infer about 4C 73.18's energy output if it is 5 billion light-years away and we can still see it?

Determining the distance to objects requires comparing how bright something appears (apparent magnitude) to how much energy it is actually emitting (absolute magnitude or luminosity). *The rule to remember is that the closer you get to a glowing object, the intensity increases rapidly!*

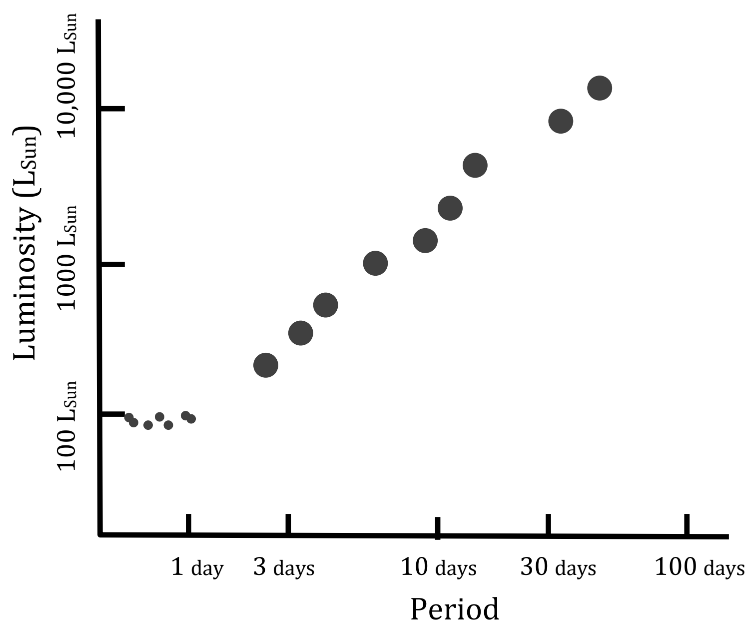
1. Imagine observing two stars with identical energy output (luminosity), Alpha and Beta. If Alpha appears to be 4 times brighter in the sky, which one is closer?

Circle one: Star Alpha Star Beta

2. Using use the $^1/_{d^2}$ rule for brightness & distance, how many times closer is this star?

Circle one: $^1/_4$ closer 2x closer 4x closer 16x closer

Astronomers are always excited when they find a variable star in a faraway cluster because there is a direct relationship between a variable star's period and its actual energy output. This is shown in the graph, known widely as the *Leavitt Law*, which allows astronomers to determine the actual energy output of a star (its luminosity).



3. Imagine observing two variable stars at the edges of two different galaxies. Star Li has a period of 8 days and Star Olanna has a period of 30 days. Using the Leavitt Law shown in the graph, approximately how many times brighter is each star compared to the Sun?

Approx. Luminosity $_{\text{Star Li}}$ = ______________ Approx. Luminosity $_{\text{Star Olanna}}$ = ______________

4. Using your best guess, about how many times more luminous is Star Reed than Star Li?

Circle one: 9x 90x 900x 9,000x

5. If these two stars <u>appear</u> to have the same apparent brightness, which one is closer?

Circle one: Star Li Star Reed

6. How many times closer is this star you selected in Question #5?

Circle one: 3x 9x 27x 81x

7. How many times farther away is the galaxy in which this star resides?

Circle one: 3x 9x 27x 81x

8. Rank order these five astronomical distance measuring techniques from closest objects to most distant objects.

Closest Objects ← ___________ ___________ ___________ ___________ ___________ → Farthest Objects

A) Supernovae

B) Bouncing radar beams

C) Parallax

D) Tully-Fisher Relation

E) Variable Stars

Astronomers use a variety of units to describe distances to objects: kilometers, astronomical units, light-years, parsecs, z-factor, among others, depending on what is most convenient.

1. Rank order the distance of these objects from Earth

Nearest to Earth ← _______ _______ _______ _______ _______ _______ _______ → Farthest from Earth

- ☐ Population I stars (Pop I)
- ☐ Large Magellenic Cloud (LMC)
- ☐ Andromeda Galaxy (Andromeda)
- ☐ Quasar
- ☐ Sun
- ☐ Virgo Galaxy Cluster (Virgo)
- ☐ Population II stars (Pop II)

2. Use arrows → to match each of these seven items with their distances.

Object		*Distance Away*
Population I stars (Pop I)		65 million light-years
Large Magellenic Cloud (LMC)		25 light-years
Andromeda Galaxy (Andromeda)		$^{1}/_{3}$ of a galaxy
Quasar		2 million light-years
Sun		8 min 20 sec
Virgo Galaxy Cluster (Virgo)		½ a local group
Population II stars (Pop II)		780 kiloparsecs

Several astronomers are arguing about their measurements of the Hubble constant. Their graphs are shown below.

1. What two things did these astronomers measure about each galaxy they were studying?

2. Rank order them from highest rate of expansion of the Universe to lowest rate of expansion.

High expansion rate ← ________ ________ ________ → Low expansion rate

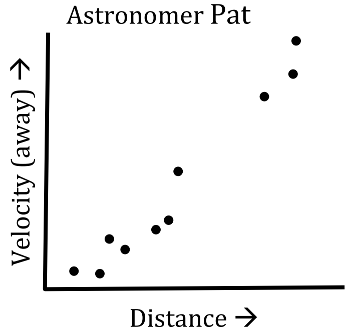
3. Rank order them from oldest age of the Universe to the youngest age of the Universe.

Old Universe ← ________ ________ ________ → Young Universe

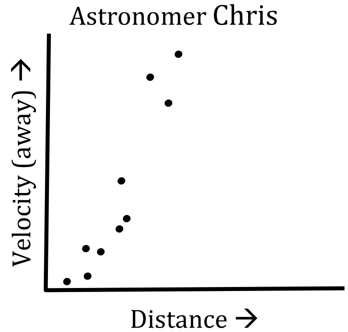
4. Rank order them from largest value of the Hubble constant to the smallest value of the Hubble constant.

Large Hubble constant ← ________ ________ ________ → Small Hubble constant

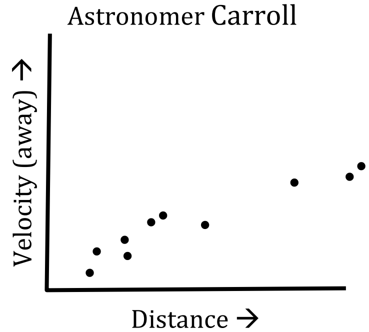
Astronomer Pat



Astronomer Chris



Astronomer Carroll



In the early Universe, the four fundamental forces played different roles in creating the Universe we see today.

1. The force between galaxies is

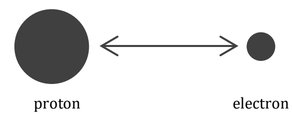
Circle one: attractive repulsive

2. The force between galaxies is

Circle one: strong weak electromagnetic gravitational

3. The force between protons and electrons is

Circle one: attractive repulsive

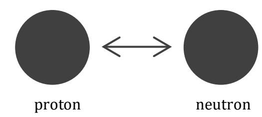


4. The force between protons and electrons is

Circle one: strong weak electromagnetic gravitational

5. The force between protons and neutrons is

Circle one: attractive repulsive



6. The force between protons and neutrons is

Circle one: strong weak electromagnetic gravitational

7. The force that controls radioactive decay of elements is

Circle one: strong weak electromagnetic gravitational

8. The force that acts over the longest distances is

Circle one: strong weak electromagnetic gravitational

9. Two astronomers are arguing about fundamental forces.

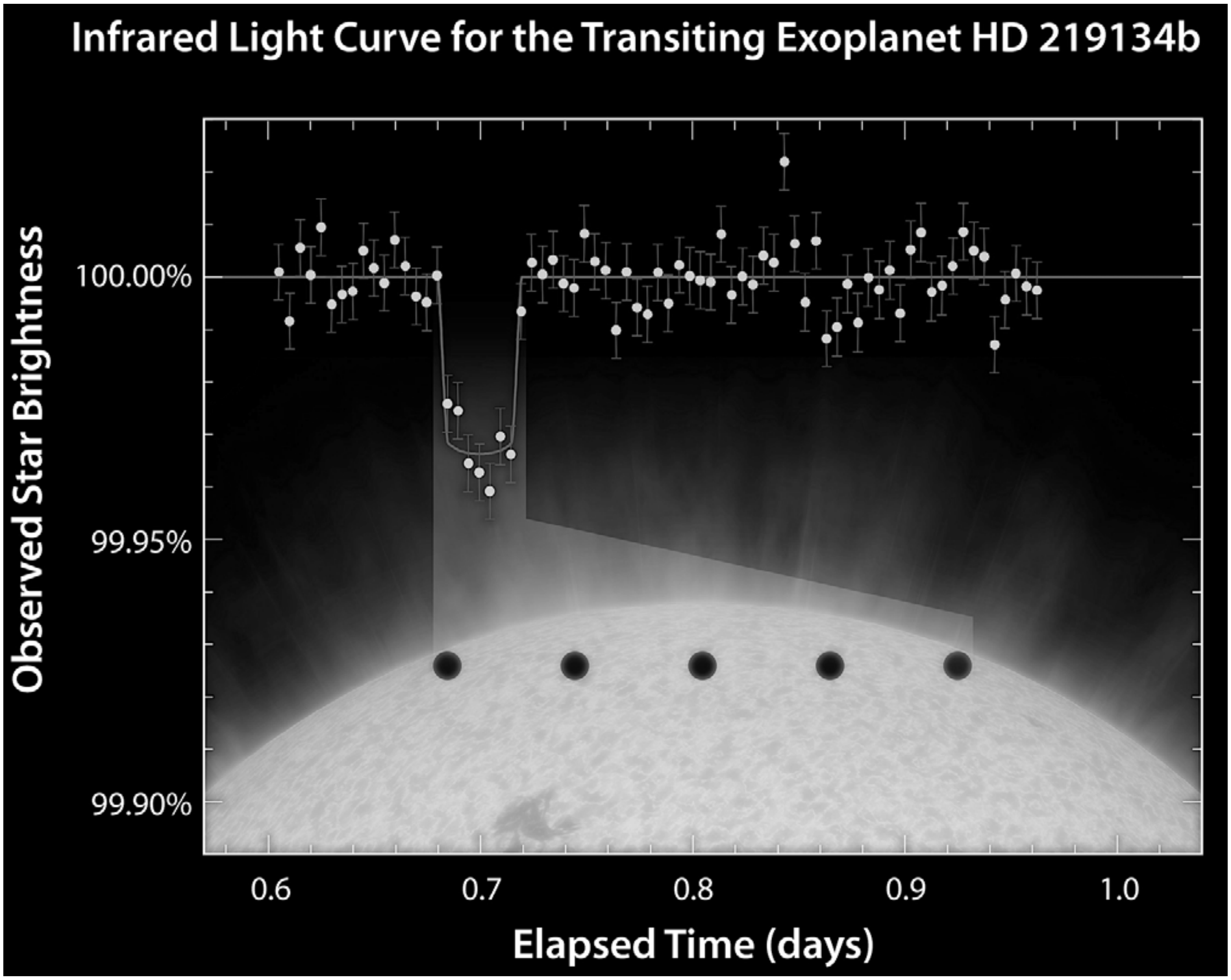
Astronomer Pat: There is no force between positively charged protons and non-charged neutrons in the nucleus of an atom because they must be "opposites to attract."

Astronomer Chris: I disagree. There must be some force that holds the nucleus of an atom together, but it cannot be electromagnetic.

With which astronomer do you agree and why? *Explain*.

Astrobiology

The most efficient strategy to find initial candidates for exoplanets orbiting other stars is the transit method. The goal is to carefully monitor the brightness of stars to see if a star dims ever so slightly when a planet passes between us and that star, blocking a tiny amount of its light.



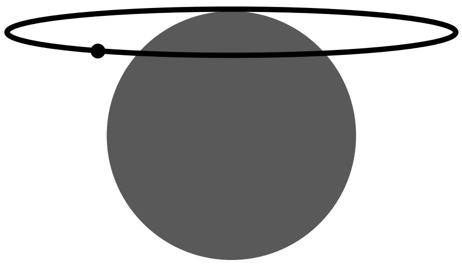
Credit: NASA/JPL-Caltech; http://www.spitzer.caltech.edu/images/6082-ssc2015-02b-Infrared-Light-Curve-for-Transiting-Exoplanet-HD-219134b

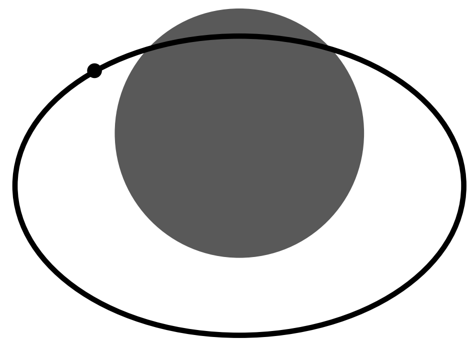
1. For the star named HD219134b, by what percentage does its light 'dim' when its orbiting planet gets between Earth and the star?

2. In this case, for how long does the star appear to 'dim'?

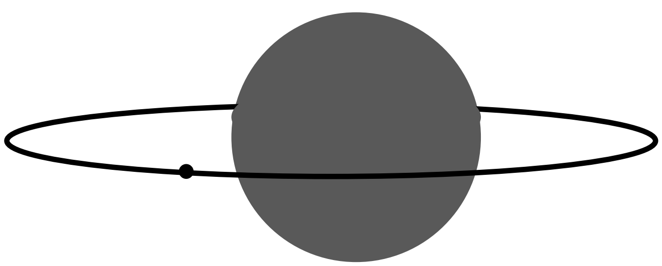
3. Which explanation better accounts for why the planet only moves across the edge of the star's face?

Circle one: explanation A explanation B





4. Sketch how the graph on the first page would look different if the exoplanet's orbit was aligned perfectly 'edge-on' as shown below.



Finding ExoPlanets Using Doppler Method 60

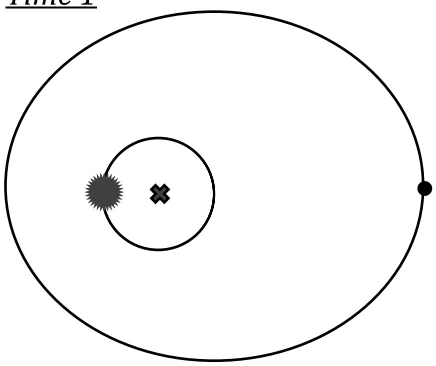
The best strategy for confirming the existence of an exoplanet and measuring its properties is to use the Doppler Method of studying the host star's changing spectra.

1. On the left-hand panels, sketch the new position of the host star due to its orbiting exoplanet's motion. (*Hint: Extend a line between the planets that goes through the system's center of mass*.)

2. On the right-hand panels, indicate if the host star's spectra will be red-shifted, blue-shifted, or not shifted.

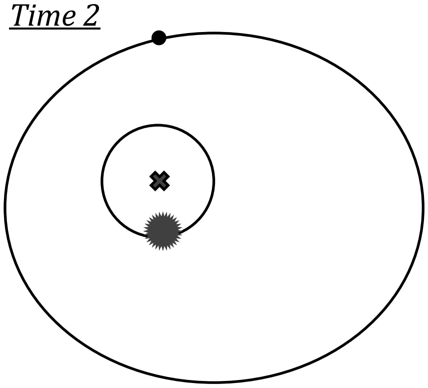
Overhead Top-View | Side-View (from Earth)

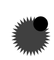
Time 1



Circle one: Red-shifted Blue-shifted Not shifted

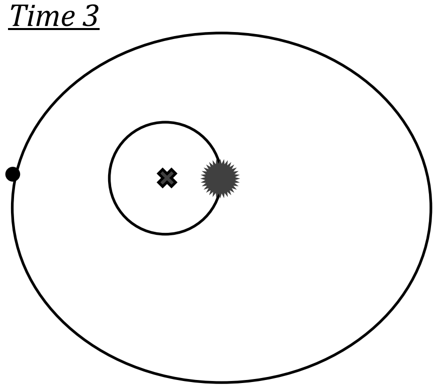
Time 2





Circle one: Red-shifted Blue-shifted Not shifted

Time 3



Circle one: Red-shifted Blue-shifted Not shifted