Name ______________________

1. Tell me about yourself:
    - Where is 'home'?
    - What are some of your interests or hobbies?
    - What is your year and major? (if undeclared, what subjects are you considering?)
    - Why are you taking this course?
    - Is there anything you are excited about in taking this course?
    - Is there anything you are worried about in taking this course or anything you want me to know?
2. List some things that come to mind when you think of astronomy
    -
    -
    -
    -
    -
3. What is astronomy? How is it different from astrology?
4. Why do you think it is important to study astronomy? Will it help you in your life?
5. Is science just a collection of facts about the universe? If not, what is it?

6. Suppose you are writing a letter to someone in an alternative universe. What would you write down as your full cosmic address/location? Be as detailed as possible, starting from our classroom and ending with the universe.

Name________________________

1. Practice with unit conversions and scientific notation:

   (a) There are 39.4 inches in 1 meter. Convert the diameter of a tennis ball, which is 2.7 inches to meters.

   (b) Write the number 863370 in scientific notation.

   (c) What is the number 4×10^6 in words?

   (d) How many years are there in 10^8 seconds?

2. In our scale model of the solar system, the sun will be represented by a tennis ball. The sun's diameter is 865,370 miles and the diameter of a tennis ball is 2.7 inches. Devise a method for calculating the scaled distance of objects in this model.

   Pick a few of your favorite objects in the solar system to calculate the scaled distance in this model:

Object	Scaled distance from sun (inches)

3. Suppose we can drive anywhere we want (on land, ocean, through space) at a constant speed of 100 miles per hour, never stopping.

   (a) About how long would it take us to drive around the Earth? (The Earth's circumference is about 25,000 miles)

   (b) About how long would it take us to drive from the Earth to the Moon (200,000 miles)?

   (c) About how long would it take us to drive from the Earth to the edge of the solar system (9 billion miles)? (Express your answer in years)

   (d) About how long would it take us to drive from the Earth to the nearest star, Alpha Centauri (25 trillion miles)? (Express your answer in years)

4. If aliens were actually visiting the Earth, how much more advanced would their technology have to be in comparison to ours? For reference, the farthest objects we have ever sent into space took over 40 years to leave the solar system.

5. What is a light year?

   Does the following statement make sense: The universe is billions of light years old. Why or why not?

6. Why is looking into space literally like looking back in time?

7. Suppose an alien named Chewbacca lives on a planet orbiting a star which is 4 light years from Earth and Groot lives on a planet orbiting a star which is 11 light years from Earth. Chewbacca and Groot both send birthday selfies to you on Earth when they each turn 20 years old. You receive both images at the same time.

   (a) Who sent their image first, or did they both send them at the same time?

   (b) Which image took longer to arrive, Chewbacca's image or Groot's image? How long did it take to arrive?

   (c) Who is older right now, Chewbacca or Groot?

   (d) What is Chewbacca's current age?
   What is Groot's current age?

   (e) If you send a happy birthday message to Chewbacca immediately after you receive his selfie, how old will he be when he receives it?

8. Ever since the 1930's our radio transmissions (including tv and satellite signals) have been blasting into space in all directions. If intelligent life exists on a planet orbiting Epsilon Eridani about 10 light years from Earth, would they know that we have become a technological species, i.e. would they detect our radio signals? If so, what are some examples of transmissions they would receive? If not, why not?

9. A cosmic calendar compresses the history of the universe into one year.
   When did the Earth form?

   About how long is a human lifetime on this scale?

   About how old are your group members?

Name ____________________

1. Fill in the blanks: The Earth __________ once per day and __________ the Sun once per year.
2. What is at your Zenith right now?
   Is your Zenith different from someone else in the class?
3. What is the ecliptic?

   Why does it not line up with the celestial equator?
4. Why do the stars appear to rise and set in the sky?
   (a) Do all of the stars you see in a given night rise and set?
   If not, what are some stars that don't set and what are they called?
   (b) If you were on the north pole, how would the stars appear to move across the sky? Where would the North star, Polaris, be located?
   (c) If you were on the equator, how would the stars appear to move across the sky?
   Where would the North star be?
5. Grand Junction is at 39°N latitude and 108.6°W longitude.
   (a) Where should you look (specify direction and altitude above your horizon) in the sky to find Polaris, the North star?
   (b) If you were to drive to Albuquerque, New Mexico, which is south of Grand Junction, how would the altitude of the north celestial pole and the star Polaris change in the sky? Will it appear higher or lower in the sky?
   (c) Would someone in Beijing, which is at 39.9°N latitude and 116.4°E longitude, see the same sky as you tonight?
   (d) Would someone in Owhango, New Zealand, which is at 39°S 175°E, see the same sky as you tonight?
   (e) If you see the constellation Sagittarius tonight near the southern horizon in Grand Junction, will you be able to see it 6 months from now?
6. Use Figure 2 to help you answer the following questions. Earth spins in the same direction as it orbits the sun.
   (a) Suppose it is midnight in June.
      - Which constellation is highest in the sky?
      - Which constellation(s) would you see setting, i.e. on your western horizon?
      - Which constellation(s) would you see rising, i.e. on your eastern horizon?

(b) Suppose it is midnight in February.

- Which constellation is highest in the sky?
- Which constellation(s) would you see setting, i.e. on your western horizon?
- Which constellation(s) would you see rising, i.e. on your eastern horizon?

7. What property of the Earth's motion causes seasons? Explain why that property causes seasons.

8. In Figure 1 label the positions of Earth when it is the Summer and Winter Solstices, and the Spring (Vernal) and Fall (Autumnal) Equinoxes. Also include the (approximate) dates when these occur.

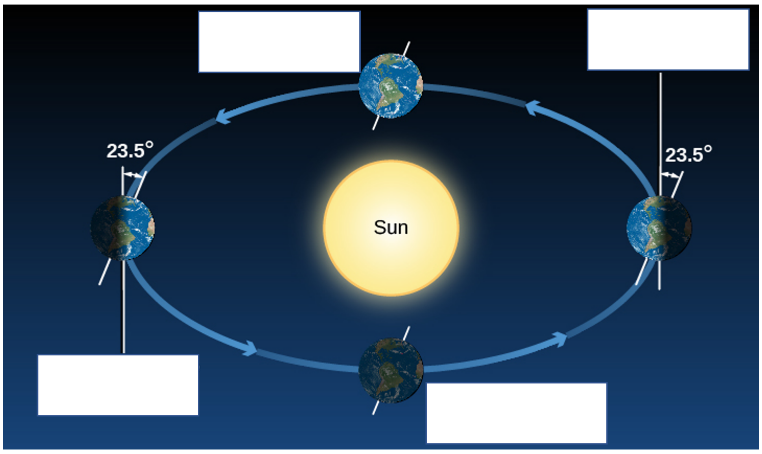

Figure 1: "Seasons" (modified by Catherine Whiting) by Andrew Fraknoi, David Morrison, and Sidney Wolff via OpenStax, licensed under CC BY 4.0

9. What would change about the Earth if its axis were tilted by 45° instead of 23.5°?

   What would change about the Earth if the ecliptic lined up with the celestial equator?

10. Where are you on Earth if you observe that:
    Your choices are: **North Pole, South Pole, North OR South pole, Somewhere on the Equator, Somewhere on Earth other than the poles or the equator**

    (a) The North star is at your zenith (directly above you):
    (b) The stars rise and set perpendicular to the horizon:
    (c) The stars circle the sky parallel to the horizon:
    (d) The celestial equator passes through the zenith:
    (e) The North star is on your horizon:
    (f) In the course of a year, all stars are visible:
    (g) The Sun sets on March 21 and does not rise until September 21:
    (h) The North star appears at an altitude of 75° above your horizon:

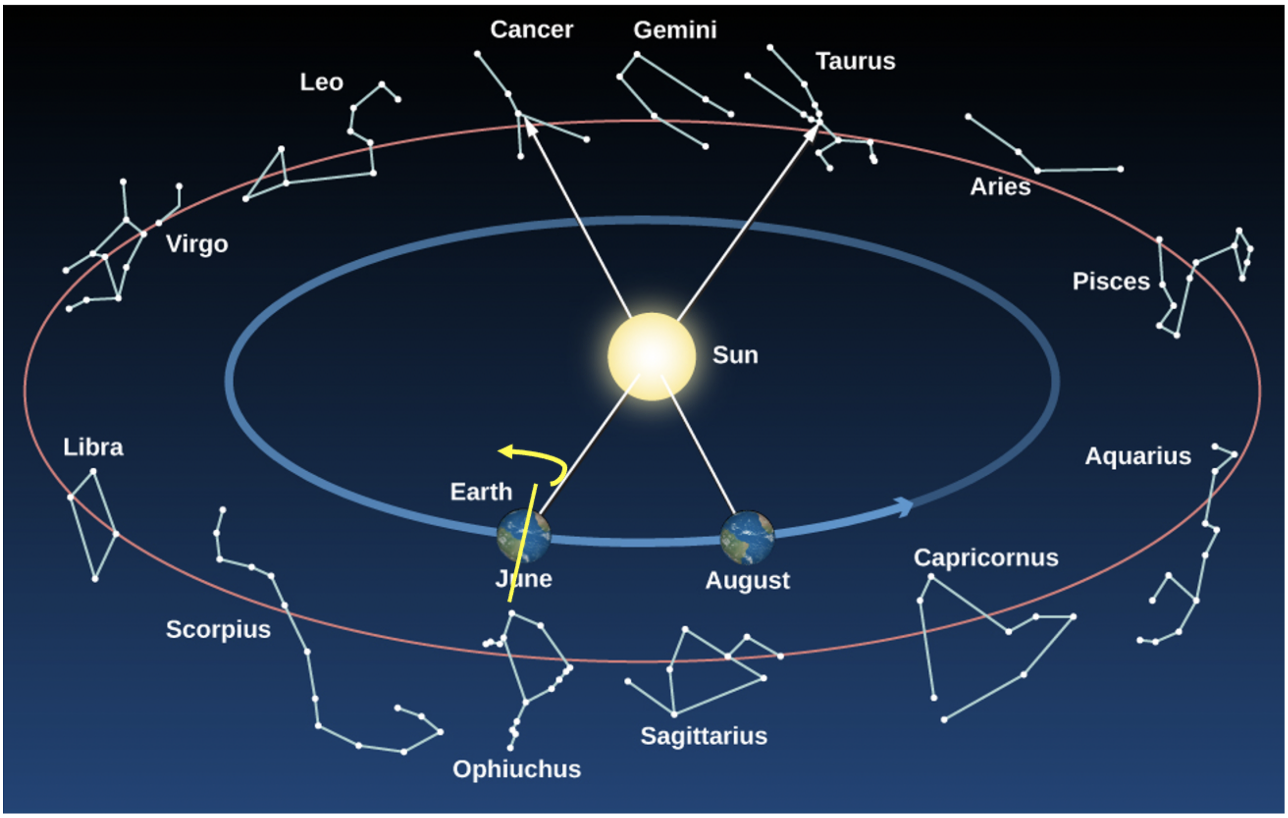

Figure 2: Earth spins counterclockwise when looking from above. "Constellations on the Ecliptic" (modified by Catherine Whiting) by by Andrew Fraknoi, David Morrison, and Sidney Wolff via OpenStax, licensed under CC BY 4.0

Name ____________________

1. Why does the moon go through phases?

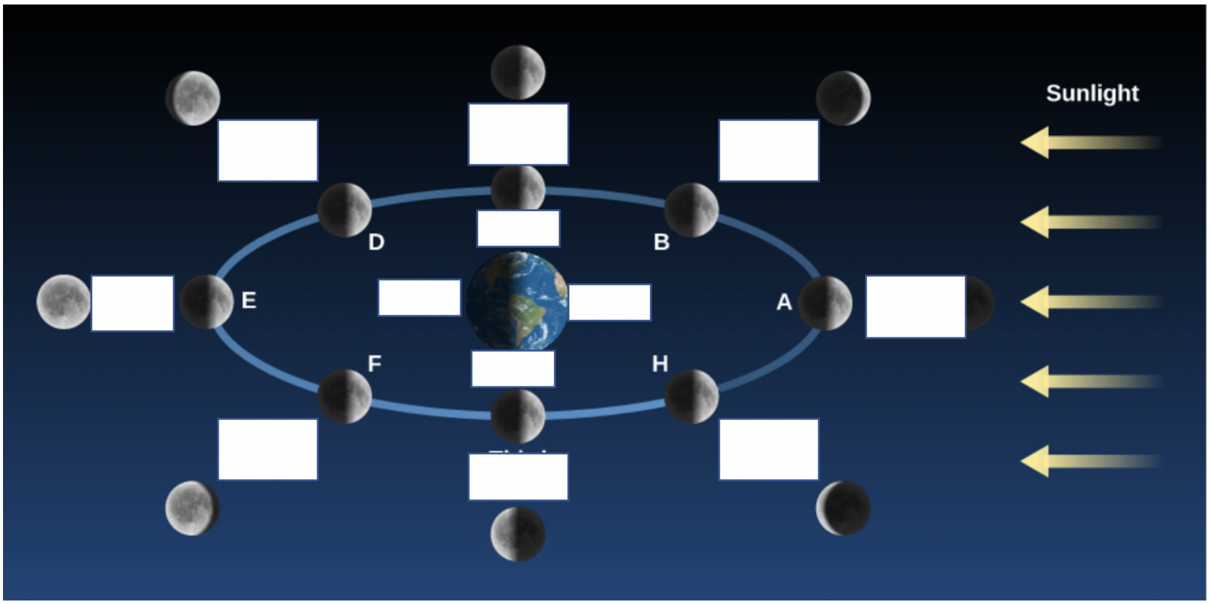

Figure 1: "Phases of the Moon" (modified by Catherine Whiting) by Andrew Fraknoi, David Morrison, and Sidney Wolff via OpenStax, licensed under CC BY 4.0

2. (a) Label the positions of the new, full, first quarter, and third quarter moons on the plot above.
   (b) There are tick marks on Earth. Label noon, midnight, 6am, and 6pm. Earth spins counterclockwise in the figure.
   (c) Why doesn't the Moon's phase change during the course of one night? Explain your reasoning.
   (d) When does a full moon rise?
   When does it set?
   When is it highest in the sky?
   Does this help explain why there is so much folklore regarding the full moon at midnight?
3. Suppose you go outside in the evening and notice that the Moon is half-light and half-dark. Is this a first-quarter or third-quarter moon?
4. You are investigating a car accident that occurred around midnight on the night of a full moon. The driver at fault claims to have been blinded momentarily by the Moon setting on the western horizon. Should you believe him?
5. If the moon appears to be in third quarter phase in the northern hemisphere, how would it appear in the southern hemisphere?
6. Why do we only see one side of the moon?

7. Suppose you are living on the moon. Let's think about what it would be like.
   How long is a day on the moon?

   Is there a 'dark' side to the moon?

   How would the Earth look?

   Would you be able to see the Earth from everywhere on the moon?

8. Discuss with your group the Arctic moon video[1]. List some things that might convince you it is either real or fake.

   Real

   -
   -
   -
   -
   -

   Fake

   -
   -
   -
   -
   -

9. How do the apparent sizes of the moon and the sun compare? Does the moon appear bigger than the sun, vice versa, or are they about the same apparent size?

10. List the two main types of eclipses and draw a diagram explaining why they occur. Indicate what phase the moon must be in for each case.

    -
    -

11. If the moon were twice the distance from the Earth as it is now, how would that affect solar eclipses?

    What if the moon were at the same distance, but twice as big as it is now? How would it affect solar eclipses?

[1] https://www.youtube.com/watch?v=pYWrQR0hLq4

Name ______________________

1. If someone from the "Flat Earth Society" tries to convince you that the Earth is flat, what are some arguments or evidence you could make to convince them that the planet is, indeed, round?
   -
   -
   -
   -

2. The ancient Greeks accepted the Geocentric model with the Earth at the center. Which objects had motion much harder to explain?
   How did the Greeks explain this motion without abandoning their model?

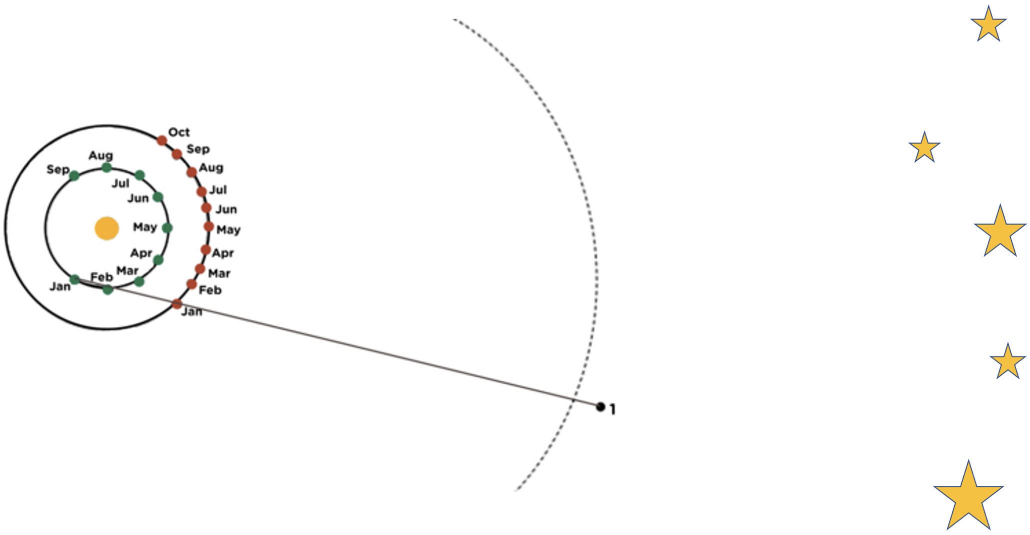

Figure 1: Retrograde Motion (modified by Catherine Whiting) by SASOL Inzalo Foundation, licensed under CC BY 3.0

3. Using the edge of a folded piece of paper or a pencil or ruler, draw straight lines connecting the line of sight of an observer on Earth to Mars in Figure 1, in relation to the background stars and label each line in sequence, i.e. 2., 3., etc. Number 1 is already done for you.
   (a) Assume upward motion is East in the figure. During which months does Mars appear to move westward?
   (b) During those months, does either planet actually move backwards?
   (c) Suppose you are on Mars. Would the Earth appear to move in retrograde motion? Hint: Extend the lines to the left side of the figure.
   Would you ever be able to see the Earth at midnight on Mars?
   (d) Do Mercury and Venus undergo retrograde motion from our perspective?
   Can you ever see Mercury and Venus at midnight?

4. The ancient Greeks did consider the possibility that the Earth orbits the sun. Why did they reject this notion and favor the Geocentric model?

5. What is stellar parallax?

   Why couldn't the ancient Greeks detect it?

6. What two observations did Galileo make with his telescope to dismiss the Greek idea that the heavens are perfect?

   -
   -

7. What two main observations led Galileo to accept the heliocentric (Sun-centered) model of the solar system? Why were the observations convincing?

   -
   -

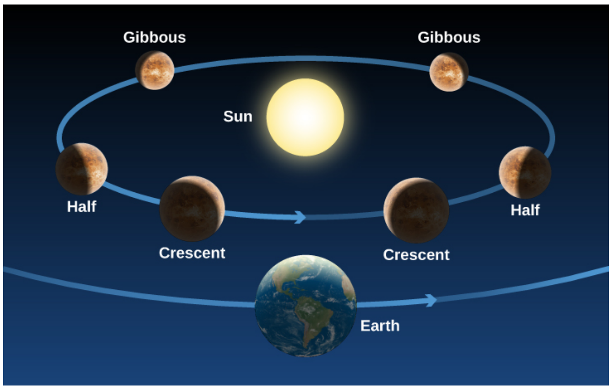

Figure 2: "Phases of Venus" by Andrew Fraknoi, David Morrison, and Sidney Wolff via OpenStax, licensed under CC BY 4.0

8. (a) Consider the geocentric model. What phases of Venus would you expect to see? Refer to Figure 2 above.

   (b) Consider the heliocentric model. Draw a similar diagram to Figure 2, but for the heliocentric model. Which phases of Venus would you expect to see?

9. What is the most convincing observation in favor of a heliocentric model (sun-centered) of the solar system, that we now have observed?

Name ____________________

1. What are Kepler's 3 laws of planetary motion?

   - 1st Law:

   - 2nd Law:

   - 3rd Law:

2. What is an Astronomical Unit?

   Earth was at perihelion on Jan 4, 2022 a distance of 147,105,052 km from the Sun and aphelion on Jul 4, 2022 at a distance of 152,098,455 km. Convert these distances to AU and comment on how much Earth varies its distance from the Sun.

   Would Earth's orbit be highly eccentric or nearly circular?

3. The diagram below shows an orbit of a comet around the sun. Each of the dots represents the position of the comet every 10 years, i.e. it will appear in position B 10 years after position A, it will be at position C 10 years after position B, etc.

   (a) Indicate where the sun would be in this diagram.

   (b) Label the points of perihelion and aphelion. Draw and label the semimajor axis.

   (c) Draw lines from point A to the Sun and point B to the sun and shade in the area. Now draw lines from points E to the Sun and points F to the Sun and shade in the area. Are the two areas roughly equal?

   (d) At which point in the orbit is the comet moving the fastest? the slowest?

   (e) At position C is the comet's speed increasing or decreasing?

   (f) What would the orbits of the planets look like, in comparison to this diagram? Sketch the orbit of the Earth to the right.

   (g) An eccentricity of 0 is a circle and a highly elliptic orbit is close to 1. The eccentricity of Earth's orbit is 0.016 and the eccentricity of Mars' orbit is 0.093. Which one would experience the largest change in orbital speed?

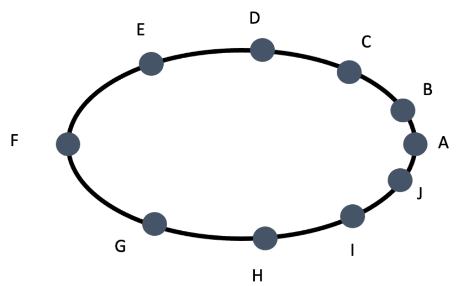

Figure 1: "Eccentric Orbit" by Catherine Whiting, licensed under CC BY 4.0

4. Comet Neowise has a semimajor axis of about 355AU.

   (a) How long does it take Neowise to orbit the sun?

   (b) Where does it spend most of its time: close to the sun, far from the sun, or about equally split? Use one of Kepler's laws to justify your answer.

5. A mystery object is observed to orbit the sun once every 45 years. Where must it be located in relation to the planets, i.e. between Mars and Jupiter, between Jupiter and Saturn, etc? A useful data table is provided below.

Planet	Mercury	Venus	Earth	Mars	Jupiter	Saturn	Uranus	Neptune
Distance from Sun (AU)	0.387	0.723	1.000	1.524	5.203	9.54	19.19	30.06
Orbital Period (years)	0.2409	0.6152	1.000	1.881	11.86	29.5	84.01	164.8

6. Look at a table of solar system data. Which planet has the largest

   (a) semimajor axis?

   (b) orbital period around the Sun?

   (c) eccentricity?

   (d) average orbital speed around the Sun?

7. What does Kepler's 3rd Law imply about the relationship between a planet's distance from the sun and its orbital speed?

   Discuss with your group ideas about why the planets might obey this relationship.

   Do Kepler's Laws apply to other objects (besides planets) orbiting the sun?

Name ________________________

1. (a) What is the difference between speed and velocity?

   (b) What is acceleration?

   (c) Brainstorm some examples of an object that is accelerating.

2. (a) Make a prediction: If we drop a hammer and a piece of paper, which one will hit the ground first? Why?

   (b) If we do the same experiment on the moon, which one will hit the ground first? Why?

   (c) Will the acceleration of the hammer be the same as on Earth?

3. The acceleration due to gravity on Earth is about $10m/s^2$.

   (a) If we drop an object on Earth, ignoring air resistance, what will be its speed when it is dropped?

   (b) Speed after 1 second?

   (c) After 2 seconds?

   (d) After 3 seconds?

4. (a) Would you weigh more or less on the moon than you do on Earth?

   (b) What about on Jupiter?

   (c) How would your mass change?

5. (a) Make a prediction: If you stand on a scale in an elevator, what would happen to the reading on the scale (your weight) as you move from the ground floor to the 4th floor?

   (b) How would your weight change when you go back down to the ground floor?

   (c) What would happen to your weight if the elevator breaks and you continue falling?

6. Give some examples of situations you have been in which you experienced weightlessness.

7. Suppose that after class you talk to your friend about astronauts in the International Space Station. Your friend asks you "Are astronauts weightless in space because there's no gravity in space?" How would you respond?

8. Do rockets need fuel to keep them moving in empty space? Explain why or why not.

9. What is Newton's 1st law?

10. Brainstorm with your group some examples of Newton's 1st law in your everyday experience.

11. What is Newton's 2nd law?

12. If two objects experience the same force, but object A is twice as massive as object B, which one will accelerate more?

13. When a bug splatters on your windshield, which is bigger: the force of the car on the bug, or the force of the bug on the car?

14. What is Newton's 3rd law?

15. What is the equal and opposite force to your weight?

    Why do we hardly ever talk about that force?

16. Which of Newton's 3 laws explains how Rockets launch off the ground?

Name ______________________

1. Momentum = mass x velocity.
   Which object would have a larger momentum: A cosmic dust particle, with a mass of $0.0001kg$ traveling at $10,000m/s$, or a bullet with a mass of $0.01kg$ traveling at $100m/s$?

2. Explain why rockets do not need fuel to keep moving in space, using the concept of momentum.

3. What keeps the Earth orbiting the Sun?

4. What keeps the Earth spinning on its axis once per day?

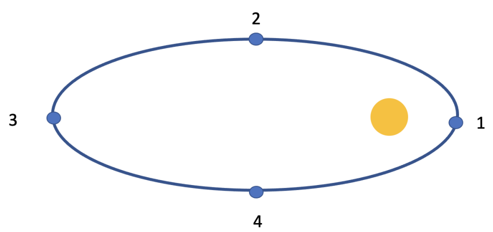

Figure 1: Orbit by Catherine Whiting, licensed under CC BY 4.0

5. Let's verify Kepler's 2nd law using conservation of angular momentum. Angular momentum = $m*v*r$, where m= mass, v = speed, r = distance to the Sun
   (a) Write an expression for the angular momentum of points 1 and 2.
   (b) Which point does the comet have the largest distance r?
   (c) Which point does the comet have the the largest speed, v?
   (d) Which point does the comet have the largest angular momentum?

6. Think of an example for each type of energy.
   - Kinetic Energy (motion)
     - Regular kinetic energy:
     - Rotational:
     - Thermal:
     - Radiative (light):
   - Potential (stored)
     - Gravitational:
     - Chemical:
     - Mass-Energy:

7. For the following situations, determine what type of energy is transferred into what type of energy
   (a) A woman is running a race.
   (b) A microwave oven heats your leftover pizza.
   (c) A nuclear power plant generates steam.
8. Consider a box moving at 3m/s on flat ground. It eventually stops moving. What happened to its kinetic energy?
9. Consider the hammer drop experiment we did where we dropped a hammer from a certain height above the ground. Describe the hammer's energy from the start of its fall to just before it hits the ground:
   (a) What kind of energy does it start with? end with?
   (b) What is its total energy at the beginning compared to the end?
   (c) What would be different if we dropped the hammer from a higher height?
10. Let's verify Kepler's 2nd law again using conservation of energy. Use Figure 1 on the previous page to answer the following questions about a comet's orbit.
   (a) Which point does the comet have the largest gravitational potential energy?
   (b) Which point does the comet have the largest kinetic energy?
   (c) Which point does the comet have the largest total orbital energy?
11. As air friction causes a satellite to spiral inwards, closer to the Earth, why does its orbital speed increase?
12. What would happen to the Earth's orbital speed if it gets closer to the Sun?
13. What is escape velocity?
14. Rank the objects according to how fast you would need to travel to escape from them, slowest to fastest: The Earth, the Moon, a black hole, the Sun, Jupiter

Name ________________

$$\text{Newton's Law of Gravitation:} \qquad F_g = G\frac{M_1 M_2}{d^2} \tag{1}$$

where $G = 6.67 * 10^{-11} \frac{N}{kg^2 m^2}$ is Newton's Gravitational Constant, M is the object mass, and d is the separation between the two objects.

1. If you and a friend were dropped off somewhere in empty space (wearing spacesuits, of course), explain what would happen to you and your friend. Would you stay at rest, move closer to each other, or farther apart?

2. Suppose two planets have masses M_1 and M_2 and are separated by a distance d.
   (a) How does the force that planet 1 exerts on planet 2 compare to the force that planet 2 exerts on planet 1?
   (b) How would the force change if M_1 is doubled, i.e. planet 1's mass is doubled?
   (c) How would the force change if the distance between the planets is doubled?

   tripled?

   halved?

   quartered?

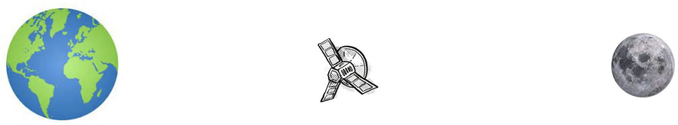

Figure 1: Newton's Law of Gravity by Catherine Whiting, licensed under CC BY 4.0

3. A spaceprobe is exactly halfway between the Earth and the Moon, as shown in Figure 1.
   (a) Which force is stronger, the force from Earth or the force from the Moon, or are they equal?
   (b) What will happen to the spaceprobe? Describe its motion.
   (c) Draw on the diagram (roughly) where you could place the spacecraft such that it will experience no net force.

4. What would happen to Earth's orbit if the sun suddenly turned into a black hole with the same mass as the sun?

5. (a) What causes tides on Earth?

   (b) Why are there two tides per day and not just one?

   (c) Would tides still occur if the Earth didn't have oceans?

   (d) Does the moon have tides?

   (e) What would change about tides if the moon were closer to the Earth?

   (f) The Sun exerts a much stronger gravitational force on the Earth than the moon. Why doesn't the Sun cause stronger tides on the Earth than the moon?

   (g) In the 2 scenarios describing Spring and Neap tides in Figure 2 below, sketch the two tidal bulges on the Earth.

   (h) In which moon phases would the Sun increase the tidal effect and make the tides slightly stronger?

   (i) In which moon phases would the Sun counter the tidal effect and make slightly weaker tides?

   (j) If the Earth did not have a moon, would we still have tides?

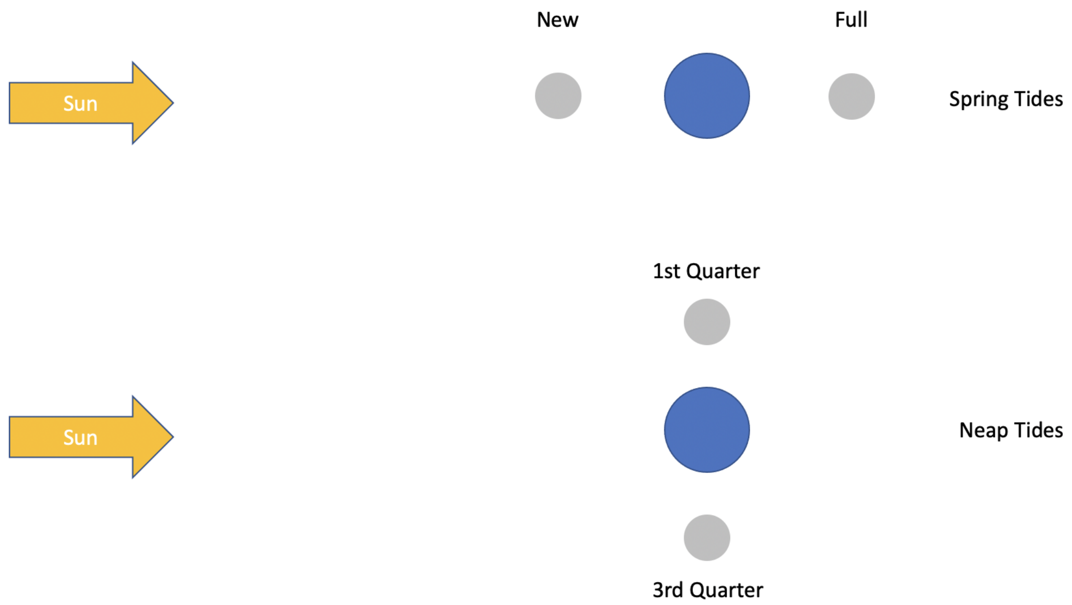

Figure 2: Tides by Catherine Whiting, licensed under CC BY 4.0

Name ____________________

1.
   - What is the wavelength of the orange wave?
   - What is the wavelength of the blue wave?
   - If the two waves have the same speed, which one has the largest frequency?
   - Which one has the largest energy?

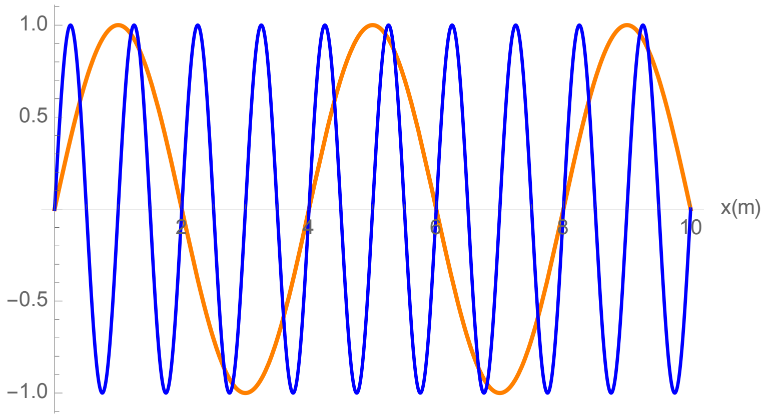

Figure 1: Waves by Catherine Whiting, licensed under CC BY 4.0

2. We categorize electromagnetic (light) waves based on their wavelength. The categories are visible light, X-rays, radio waves, ultraviolet, infrared, gamma rays, and microwaves.
   - List the types of electromagnetic waves in order of smallest **wavelength** to largest, including visible (red and blue) light.
   - List the types of electromagnetic waves in order of smallest **frequency** to largest.
   - List the types of electromagnetic waves in order of smallest **energy** to largest.

3. Why is it dangerous to be exposed to X-rays but not as dangerous to be exposed to radio waves?

4. Your group is part of a federal funding agency evaluating proposals to build a new telescope. In each case you can only fund one proposal. Explain which one you would choose and why.

   (a) Proposal A: An X-ray wavelength telescope, located in Antarctica at a cost of $500 million OR Proposal B: A visible wavelength telescope placed on a satellite in orbit about the Earth at a cost of $1 billion.

   (b) Proposal C: A visible wavelength telescope located on a university campus for $ 1 million OR Proposal D: A radio wavelength telescope located in the desert for $10 million

5.
   - If an object emits light of only blue wavelengths, what color would it look like?
   - If an object emits both green and red light, what color would it look like?
   - What color do we see if an object emits light of all visible wavelengths?
   - If an object absorbs all colors except red, what color would it look like?
   - Why does Mars appear red?
   - Why is the sky blue?

6. What is a spectrum?

7. Make a sketch of each type of spectrum and give an example of an object or situation that would emit such a spectrum.
   - Continuous
   - Emission Line
   - Absorption Line

8. Why does an emission spectrum reveal the chemical composition of an object?

9. Why does an absorption spectrum reveal the chemical composition of an object?

Name ______________________

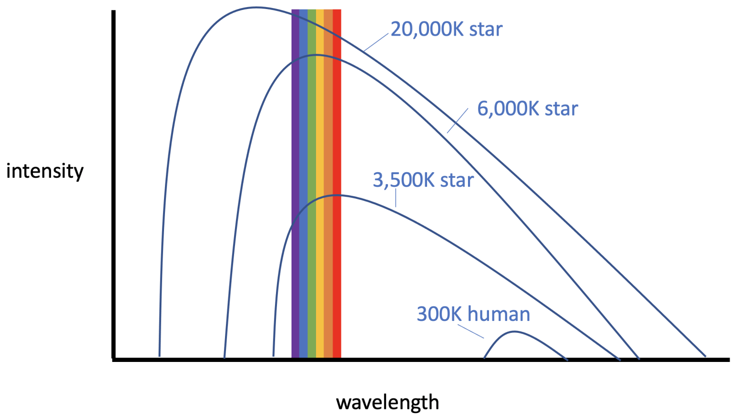

Figure 1: Spectra of Stars by Catherine Whiting, licensed under CC BY 4.0

1. For the following questions refer to Figure 1.

   (a) What type of electromagnetic radiation does the 20,000K star emit most intensely?
   What color would the star appear to our eyes?

   (b) What type of light does the sun emit the most intensely?
   What color does it appear to our eyes?

   (c) What type of electromagnetic radiation does the 3,500K star emit most intensely?
   What color would the star appear to our eyes?

   (d) If all three stars were the same distance from us, which one will appear the brightest?

   (e) Which star emits the most red light?
   The most blue light?

   (f) How could you 'see' a person on a dark night?

2. Suppose the surface temperature of the Sun were about 12000K, rather than 5800K. How do you think that would affect life on Earth?

3. 5 space probes at the distances shown in Figure 2 broadcast a radio signal towards Earth at 500MHz. The length of the lines indicate speed of the probe. Rank the signals received by Earth smallest to largest frequency.

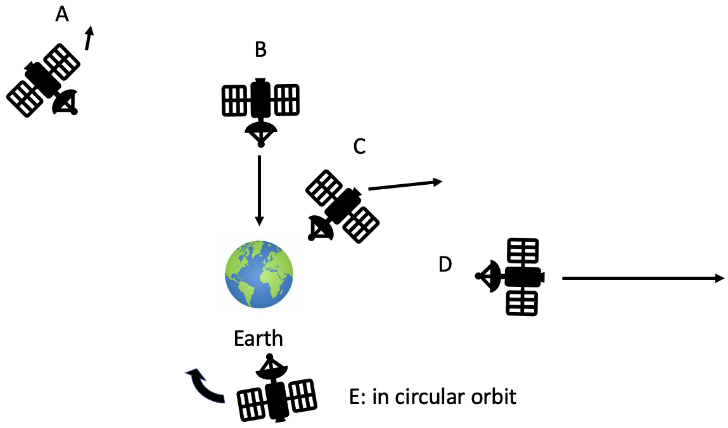

Figure 2: Doppler Effect by Catherine Whiting, licensed under CC BY 4.0

4. You observe the light from stars A, B, and C and you notice:

- Star A's spectrum peaks at about 560nm and you observe an emission line at 656.2nm.
- Star B appears very reddish in color and there is an emission line at 658.1nm
- Star C's spectrum peaks at about 400nm and there is an emission line at 656.8nm.

Note that Hydrogen has an emission line at 656.5nm in the lab.

(a) Which star is the hottest?

Which star is the coolest?

(b) Which star(s) are moving towards us?

Which star(s) are moving away from us?

Name ______________________

1. What are terrestrial planets? List the terrestrial planets and where they are located in the solar system (near/far from the sun or both).

2. What are Jovian planets? List the Jovian planets and where they are located in the solar system.

3. Compare the terrestrial to Jovian planets (i.e. big/small in size, high/low density)

Characteristic	Terrestrial	Jovian
Size and mass		
average density		
Composition (rocky/ gaseous)		
Solid surface?		
Moons?		
Temperature		

Are there any exceptions to the characteristics above?

4. Consider some general characteristics of the orbits of the planets in the solar system.
   (a) Do the planets orbit in random directions?
   (b) Are the orbits highly elliptical or almost circular?
   (c) What about the direction of rotation of the planets and their moons?
   (d) Are there any exceptions to these general features?

5. (a) What are asteroids?
   (b) Where are asteroids mostly found in the solar system?
   (c) What are comets?
   (d) Where are comets mostly found in the solar system?

6. Briefly explain how the nebular theory explains each observation and provide an example or piece of evidence in support of the explanation.
   (a) Orderly motion of the planets and moons.

(b) Why are there 2 types of planet (terrestrial and Jovian)? Let's answer this in several parts:

i. What is the frost line and where do you think it is located?

ii. How did rocky terrestrial planets form and why were they small?

iii. How did gaseous Jovian planets form and why were they large?

(c) Where did the asteroids and comets come from?

(d) Exceptions to the rules above (i.e. why does Uranus spin sideways, Venus backwards?)

How do we think Earth's moon formed?

7. Suppose we find four different planetary systems with the properties described. (These are not real discoveries.) Decide whether the discovery should be considered reasonable or surprising in the context of the nebular theory. Explain your reasoning.

(a) System A has three large jovian planets in its inner solar system and six small terrestrial planets in its outer solar system.

(b) System B has five Earth-size terrestrial planets. Each of the five planets has a moon that is nearly the same size as Earth's Moon.

(c) System C has six terrestrial planets in its inner solar system and four jovian planets in its outer solar system.

(d) System D has eight planets that all orbit in random directions and in different planes.

8. Given what we learned about how our solar system likely formed, what is your reaction to the evidence that exoplanets (planets orbiting other stars) exist in abundance? Is it surprising or reasonable?

Name ______________________

1. Consider the surfaces of the terrestrial planets (and Earth's moon).
   (a) Which ones are heavily cratered?
   (b) Which ones seem to have lots of geologic activity (volcanoes, erosion)?
   (c) Based on this, what characteristic of planets seems to contribute most to geological activity?
   (d) Why is that characteristic so important?
2. List the three main components of Earth's interior in the order of lowest density to highest. Comment on the location of these components (outer, middle, inner).
   -
   -
   -
3. Why does the Earth's interior have the structure that it does?
4. What must have been true about the Earth in order for differentiation to have occurred?
5. What 2 conditions are needed to create a planetary magnetic field?
   -
   -
6. What is the magnetosphere and why is it important for a planet to have?

7. List some main geological processes that can occur on a planet and give an example of each.
   -
   -
   -

8. What are plate tectonics and what are they responsible for?

9. Label which figure represents a Rift Zone and which represents a Subduction Zone and briefly explain what each one is.

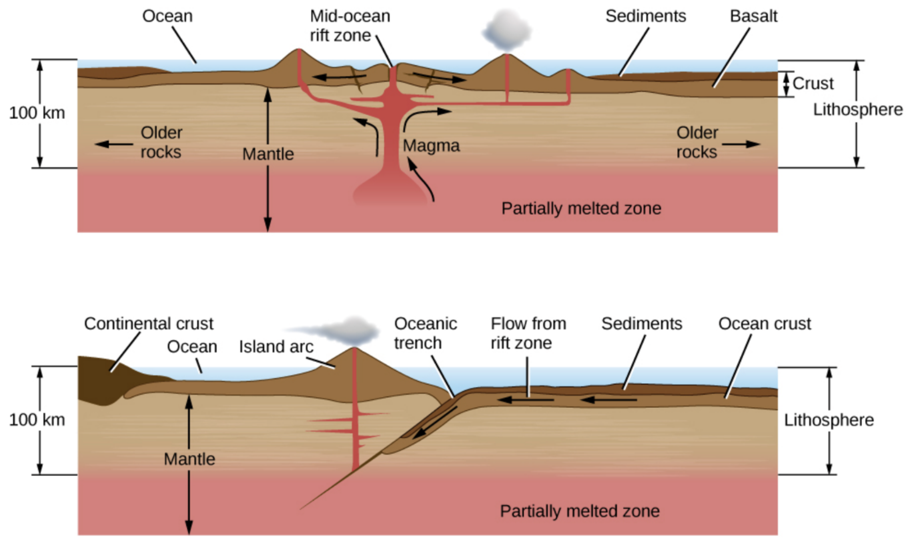

Figure 1: "Rift Zone and Subduction Zone." (modified by Catherine Whiting) by Andrew Fraknoi, David Morrison, and Sidney Wolff via OpenStax, licensed under CC BY 4.0

10. List some reasons why we need Earth's atmosphere to survive.
    -
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    -
    -

11. What does a planet need in order to create an atmosphere?

    What does a planet need in order to maintain an atmosphere?

12. Why are the moon and Mercury effectively 'dead' geologically speaking?

13. Suppose another star system has a rocky terrestrial planet that is half the size of Earth, 1/5 the mass, and at the same distance from its star, which is similar to our sun. Describe the type of geology you would expect this planet to have. Would you expect it to have an atmosphere?

Name ______________________

1. Mars has been the subject of more than 50 spacecraft missions. It is about half the size and about 1/10th the mass of the Earth, and located 1.5AU from the Sun.

   (a) Why has Mars gotten so much attention?

   (b) Does Mars have volcanoes? If so, are they still active?

   (c) Does Mars have evidence of tectonic activity, past or present?

   (d) What evidence or geologic features suggest Mars once had surface liquid water?

   (e) Mars does not have an active magnetic field. What evidence suggests it might have had one in the past?

   (f) What is the atmosphere of Mars like?

   (g) Why did Mars lose most of its atmosphere?

2. Venus and the Earth are almost identical in size, so we should expect them to have similar geologies and atmospheres. However, Venus is located at 0.723AU, while Earth is at 1AU from the sun. Let's compare some properties of Venus vs. Earth:

   (a) Does Venus have significant impact cratering on its surface?

   (b) Does Venus have volcanoes? If so, how frequent compared to the Earth?

   (c) Does Venus have tectonic activity?

   (d) Does Venus have erosion? Why or why not?

   (e) What is the atmosphere of Venus like?

3. What is the greenhouse effect? What gasses are the main greenhouse gasses?

4. Why does the atmosphere of Earth differ so much from Venus and Mars?

5. Suppose Earth were moved to the location of Venus. What would happen to the Earth?

6. Climate skeptics often claim that the explanation for Earth's recent increase in average surface temperature is due to increases in the Sun's brightness and changes in the tilt of Earth's axis. What sort of effects those could have on the Earth? Could they explain the increase in Earth's average temperature over the past 100 years?

7. List some basic properties of the Earth that make it *unique* amongst the terrestrial bodies and why it can support life.

    -
    -
    -
    -

8. Decide whether each of the following potential discoveries would be expected or surprising.

    (a) We find a planet that is the same size as the Earth but as heavily cratered as the Moon.

    (b) New data reveal that Venus has an erupting volcano.

    (c) New spacecraft images of Mercury reveal evidence of past liquid water on its surface.

    (d) A new planet is discovered that is similar to Earth and has an Earth-like atmosphere containing lots of oxygen, but no signs of life are detected.

9. If you were searching through a list of discovered exoplanets and their properties for humans to colonize, what two properties would you focus on? Assume that the host star is similar to our sun.

Name ______________________

Planet	Distance (AU)	Diameter (km)	Mass (Earth = 1)	Density (g/cm^3)	Rotation (hours)	Axial Tilt (°)
Jupiter	5.2	142,800	318	1.3	9.9	3
Saturn	9.5	120,540	95	0.7	10.7	27
Uranus	19.2	51,200	14	1.3	17.2	98
Neptune	30.0	49,500	17	1.6	16.1	29

1. What are the main differences and similarities between the four Jovian planets? Which ones are most similar to each other?

2. Jupiter is about 3.3x more massive than Saturn. Why is it only about 20% bigger than Saturn?

3. Which of the Jovian planets have magnetic fields? Which one is the strongest and why?

4. What is the main difference between Jupiter/Saturn and Uranus/Neptune when it comes to their interior composition?

5. (a) Why do Jupiter and Saturn appear red/white?

   (b) Why do Uranus and Neptune appear blue?

6. (a) What is the Great Red Spot on Jupiter?

   (b) What is the main reason Jupiter has strong storms?

(c) Do all of the Jovian planets have strong storms and wind?

(d) Which of the Jovian planets have seasons? What property of the planets causes seasons?

7. (a) Are Saturn's rings solid?

(b) What are the rings composed of?

(c) Why are there gaps in the rings of Saturn?

(d) Why don't the rings of Saturn form a moon?

8. What are the two hypotheses that explain how rings form?

-
-

9. Why do all of the Jovian planets have rings?

10. Why do we expect to see the rings of Saturn for only the next few hundred million years?

11. Suppose we discover a new planet that formed with no moons. Would it be surprising or expected if we discover rings around this planet?

Name ____________________

1. Which of the Jovian planets have large moons (about the size of Earth's moon)?

2. (a) Rank the four Galilean Moons of Jupiter based on size.
   (b) Now rank them based on their amount of geologic activity. What is surprising about this?
   (c) What makes Io hot enough to have volcanoes?

3. Scientists strongly suspect that Europa has a subsurface ocean, even though we can't directly see below the icy surface. Explain why scientists think this ocean exists.

4. Consider the table below listing the Galilean moons of Jupiter, their average distance from Jupiter and their densities. Do you notice a trend in the data? Hypothesize a possible explanation for this trend. Note that the density of rock is $3.5 g/cm^3$ and the density of ice is $0.9 g/cm^3$.

Moon	Distance ($1000 km$)	Density (g/cm^3)
Io	421.6	3.57
Europa	670.8	2.97
Ganymede	1070	1.94
Callisto	1883	1.86

5. Why are small icy moons more geologically active than small rocky moons/planets?

6. The terms asteroid, meteoroid, meteor, and meteorite often are used interchangeably, but they have different meanings in astronomy, even though they all refer to the same types of objects:
   An **asteroid** = a large rocky object, typically found in the asteroid belt
   A **meteoroid** = a small rocky object moving through space
   A **meteor** = a meteoroid that enters Earth's atmosphere creating a bright streak in the sky (also called a shooting star).
   A **meteorite** = a leftover piece of a meteor that was big enough to make it through Earth's atmosphere and hit the ground.
   (a) If you find a rock on the ground that came from space, what would you call it? __________
   (b) Last night I saw a bright __________ in the sky when I was stargazing.
   (c) A(n) __________ is discovered to be on a collision course with Earth in 2030.

7. Why is there an asteroid belt?

8. (a) Do all comets have tails?

   (b) Approximately how close to the Sun does a comet have to be in order for a tail to form?

   (c) In which direction does the tail point?

9. The following is an orbit of a comet around the sun. Which of the locations will the comet have a tail? For each of those locations, sketch the direction of the tail.

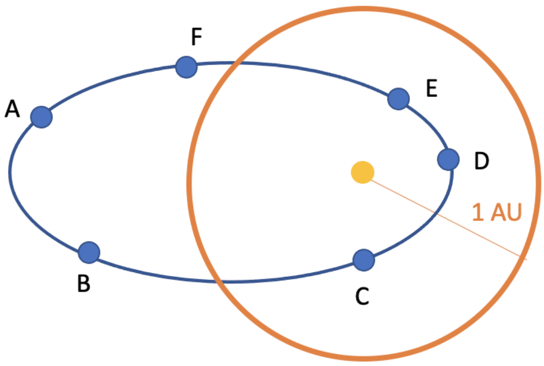

Figure 1: Comet Tail by Catherine Whiting, licensed under CC BY 4.0

10. (a) What is a meteor shower?

    (b) Why is there a meteor shower every year on August 10th, 11th, and 12th?

11. (a) List some properties of Pluto that make it different from the other planets.

    -
    -
    -
    -

12. In 2006 the International Astronomical Union made the decision to "demote" Pluto to a new category of Dwarf Planet. Discuss with your group whether you agree with this decision or not. What led astronomers to make this controversial decision?

Name ______________________________

1. When was the first extrasolar planet (exoplanet) discovered?
2. What are two reasons why it would be extremely hard to detect planets orbiting around other stars?
   -
   -
3. What are the main properties of a planet that we would like to determine, and why are those properties important?
4. Briefly summarize the three exoplanet detection methods and what properties of a planet each one can determine.
   - Direct Imaging

     Why is direct imaging done using infrared telescopes?
   - Doppler Method (radial velocity)
   - Transit Method

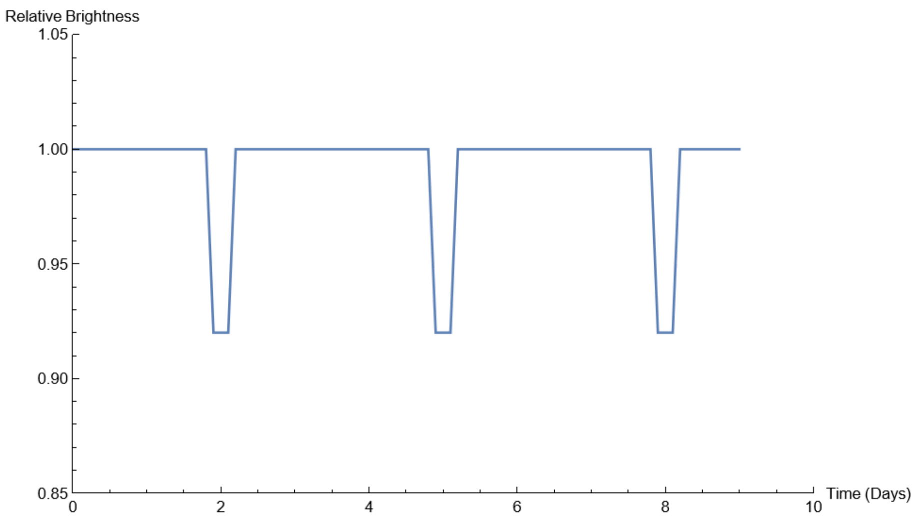

Figure 1: Light Curve by Catherine Whiting, licensed under CC BY 4.0

5. The light curve for an exoplanet is shown in Figure 1.
   (a) What is the orbital period of the planet?
   (b) Discuss with your group a way you could use this light curve to determine the size of the planet, relative to the size of its star.

6. Make a sketch of what you think a light curve (plot of brightness vs time) would look like for a star that has two planets of different sizes.

7. Suppose aliens are trying to discover planets in our solar system using the transit method.
   (a) Where must they be located, relative to our solar system's orbital plane?
   (b) Which planets would be easiest to detect?

8. (a) What are hot Jupiters?
   (b) Why do they challenge the nebular theory of solar system formation?
   (c) What do we think could explain their existence?

9. So far we have not detected any Earth-size planets in Earth-like orbits. Does this tell us that Earth-like planets must be very rare?

10. (a) When did life arise on Earth and how do we know?
    (b) Compare this to the age of the Earth. How do you think this affects the possibility of finding life in the universe?
    (c) Roughly how long did it take complex life to evolve?
    (d) Do you think simple life or complex life would be more common in the universe?

11. (a) What is the habitable zone around a star?
    (b) Where is the habitable zone around our star?

12. The Drake equation provides a way to estimate the number of intelligent civilizations in our galaxy:

$$N_{\text{civilization}} = R_{\text{total}} * L, \qquad R_{\text{total}} = R_{\text{star}} * f_{\text{p}} * f_{\text{e}} * f_l * f_i * f_c \tag{1}$$

Write what each of the quantities in the equation correspond to:
L=
R_{star} =
f_{p} =
f_{e} =
f_l =
f_i =
f_c
Suppose that new stars like the sun form at a rate of about 10 per year. Now suppose that 3 out of 4 of those stars has planets, 1 in 8 of those are habitable, 4 in 5 of those support life, 1 in 5 of those develop intelligent life, and 3 in 5 of those develop communication technology. What is the rate (number/year) R_{total} at which these civilizations are produced? How many civilizations would exist at present in our galaxy, if the lifetime of a civilization is 1000 years?

13. If you wanted to send a message to a distant planet, what type of light (X-ray, visible, radio, etc?) would you want to send the signal?
Discuss with your group: Do you think it would be a good idea to send a message to other star systems?

14. The Fermi paradox is essentially: 'Where are all the aliens? Why haven't we been contacted yet?' List a few possible solutions to the paradox. What do you think is the most likely solution to the Fermi paradox, in your opinion? Discuss with your group.

Name ____________________

1. Order the layers of the Sun from inward to outward and briefly describe each layer, including the temperature. (Photosphere, Chromosphere, Core, Corona, Radiation Zone, Convection Zone)
   -
   -
   -
   -
   -
   -

2. List the main types of solar activity and briefly describe them.
   -
   -
   -
   -

3. Why do sunspots appear dark? Is there no light being emitted from those regions of the Sun?

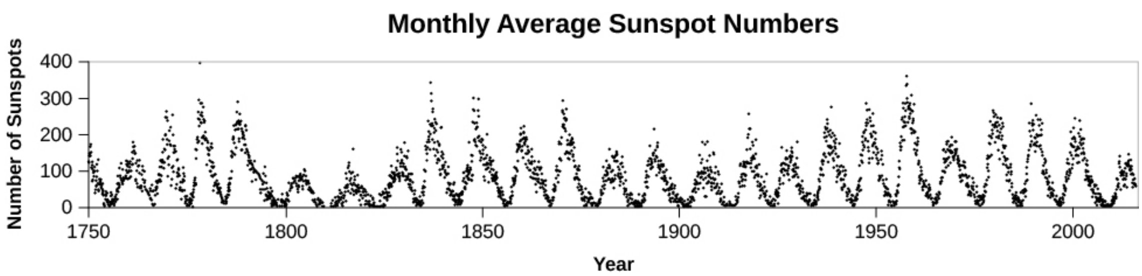

Figure 1: "Numbers of Sunspots over Time." by Andrew Fraknoi, David Morrison, and Sidney Wolff via OpenStax, licensed under CC BY 4.0

4. (a) Based on Figure 1, what is the time period between one solar maximum and the next?
   (b) When was the last solar maximum?
   (c) Approximately when should we expect to see the next maximum?

5. What do we think causes solar activity (sunspots, flares, prominences)?

6. How do magnetic fields explain why sunspots are dark?

7. Why is the solar cycle sometimes called a 22 year cycle?

8. What effects does the solar cycle have on the Earth, if any?

9. What keeps the sun shining? Briefly describe how the process works.

10. What prevents the sun from collapsing due to its strong gravity?

11. Describe the solar thermostat:

    - What would happen if the sun's core cools slightly?

    - What would happen if the sun's core heats up slightly?

12. (a) How long will fusion of Hydrogen into Helium happen (in total) for the sun?

    (b) If the sun has been fusing for about 5 billion years, how much longer will it last?

    (c) What do you think will happen to the sun's core when the Hydrogen fuel runs out?

Name ____________________

1. (a) Why is mass the most important property of a star in determining how long it will live?

   (b) Why do very massive stars live very short lives if they have so much more 'fuel' to burn?

2. (a) If a star appears red, would it live a long or short life compared to the sun?

   (b) What about a blue star?

3. How do stars form?

4. (a) Why is the lower limit to a star's mass about 0.08 times the mass of the sun?

   (b) Why is the upper limit to a star's mass about 300 times the mass of the Sun?

5. What are brown dwarfs?

6. What event triggers the beginning of the death of all stars?

7. Rank the following stars according to their age, youngest first. They all have the same mass as the sun.

   (a) Star A is fusing hydrogen into helium in its core.

   (b) Star B is fusing hydrogen into helium in a shell around its core and in its core helium is fusing into carbon.

   (c) Star C is composed primarily of Carbon and has no nuclear reactions ongoing in its core.

8. Suppose only low mass stars could exist. Would elements heavier than carbon exist?

9. Why can a star of about 6 times the mass of the sun produce Oxygen, but a star the mass of the sun cannot?

10. Why can elements heavier than iron NOT be fused in the cores of stars?

11. Fill in the table:

	Mass Range	Lifetime	Fusion End Product	Remnant
Low Mass Stars				
Intermediate Mass Stars				
High Mass Stars				

12. What will remain of the sun after it dies?

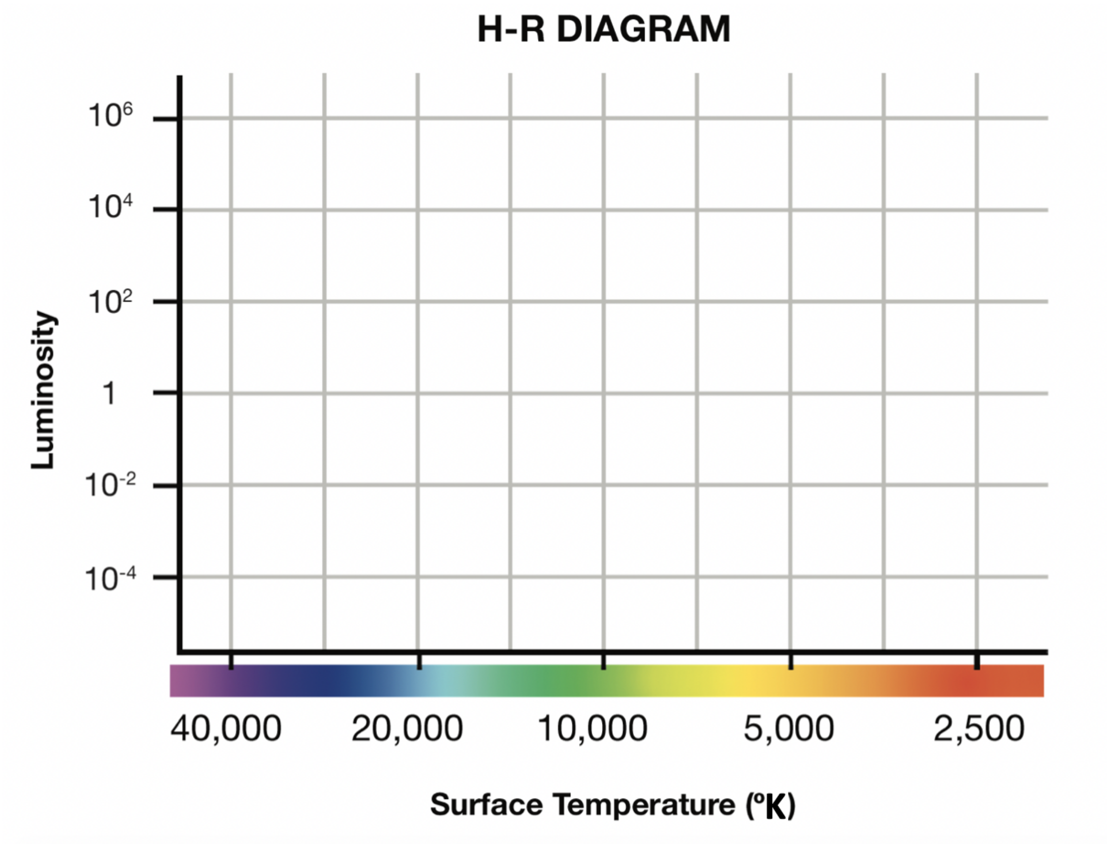

Figure 1: Blank HR Diagram by Catherine Whiting, licensed under CC BY 4.0

Stage	Time in This Stage (years)	Surface Temperature (K)	Luminosity (L_{Sun})	Diameter (Sun = 1)
Main sequence	10 billion	5800	1	1
Becomes red giant	1.3 billion	3100 at minimum	2300 at maximum	165
Helium fusion	100 million	4800	50	10
Giant again	20 million	3100	5200	180

13. The table above shows the properties of a star with the same mass as the Sun on its evolution to a white dwarf. Plot and label those stages of the star on the blank HR diagram in Figure 1.

Name ______________________

1. What do astronomers mean when they say, ‘we are made of star stuff’?

2. (a) What is a white dwarf?

   (b) About how big is a typical white dwarf?

3. (a) What is a neutron star?

   (b) About how big is a typical neutron star?

   (c) How do we know neutron stars exist?

4. (a) What is a pulsar?

   (b) How do we know that pulsars are neutron stars?

5. (a) What is a black hole?

   (b) Are black holes vacuum cleaners sucking up all the material around them?

   (c) What would happen to the orbit of the Earth if the Sun were to suddenly become a black hole?

6. Partner A will take a journey into a black hole. Partner B will stay safely away from the black hole and watch. Partner A will carry a clock and emit a blue light signal every 10 minutes towards Partner B.

   (a) Describe what Partner A will observe as they fall in.

(b) Describe what Partner B will observe as Partner A falls in.

7. Which are more common: white dwarfs, neutron stars, or black holes?

8. Star X is about 7 times the mass of the sun. Will it become a white dwarf, neutron star, or a black hole?

9. Rank the following objects based on their size, smallest (1) to largest (4):

   - $1.2M_{sun}$ white dwarf
   - Jupiter
   - $0.6M_{sun}$ white dwarf
   - $1.5M_{sun}$ neutron star

10. We do not know yet how likely life might evolve on other planets. For sure, some stars are very unlikely to harbor life. For each of the three candidate stars, state whether you think it would be possible for advanced life to evolve on a planet orbiting the star. Assume each star does not have a companion star.

    - A $9M_{sun}$ main sequence star
    - A $2M_{sun}$ black hole
    - A $0.7M_{sun}$ main sequence star

Name ______________________

1. On Figure 1 of the schematic diagram of the Milky Way, seen edge on, label the following: Disk, Bulge, Halo, Globular Clusters, Sun's Approximate location.
   What is the halo of a galaxy?
   What are globular clusters?

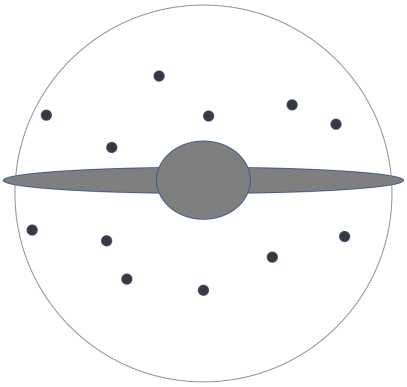

Figure 1: Schematic of Milky Way Galaxy by Catherine Whiting, licensed under CC BY 4.0

2. List some evidence pointing to our Milky Way Galaxy being a spiral galaxy.
   -
   -
   -

3. (a) Are the orbits of stars in the disk random or orderly?

   (b) Are the orbits of stars in the halo and bulge random or orderly?

4. Where does star formation typically occur in a spiral galaxy?

5. Why are the spiral arms of a galaxy typically pink, i.e. blue/white and red colored?

6. (a) Why can't we see the center of the galaxy with visible light?

   (b) What wavelengths of light can we use to probe the center of our galaxy?

   (c) What is at the center of our galaxy? How do we know?

7. Figures 2 and 3 show examples of very typical elliptical and spiral galaxies, respectively.

   (a) Using those two images, characterize elliptical vs spiral galaxies, i.e.: How much gas and dust do spiral galaxies have in comparison to ellipticals?

   (b) What color are spiral galaxies, typically?

   (c) What color are elliptical galaxies?

   (d) Explain why they tend to have these colors.

   (e) How does this relate to the age of the galaxies?

Figure 2: Elliptical Galaxy NGC 4150 by NASA, ESA, R.M. Crockett (University of Oxford, U.K.), S. Kaviraj (Imperial College London and University of Oxford, U.K.), J. Silk (University of Oxford), M. Mutchler (Space Telescope Science Institute, Baltimore, USA), R. O'Connell (University of Virginia, Charlottesville, USA), and the WFC3 Scientific Oversight Committee, licensed under CC BY 4.0

Figure 3: Spiral Galaxy M101 by ESA/Hubble, licensed under CC BY 4.0

Name ____________________

1. Refer to Figure 1 for this question.
   (a) A galaxy's redshift is measured and its velocity away from us is calculated to be 15,000km/s. How far away is it?
   (b) A galaxy is determined by a white dwarf supernova to be 30 million light years away. How fast must it be moving away from us?

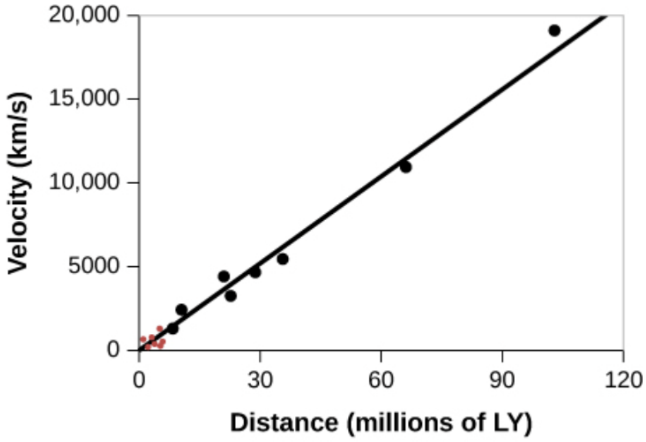

Figure 1: "Hubble's Law" by Andrew Fraknoi, David Morrison, and Sidney Wolff via OpenStax, licensed under CC BY 4.0

2. For the following objects, which method of distance measurement would you use to measure the distance to the object?
   - Andromeda Galaxy
   - Earth's Moon
   - A very old cluster of galaxies
   - Alpha Centauri (closest star)
   - A galaxy with a very large redshift

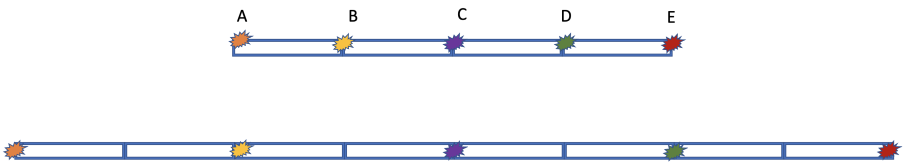

Figure 2: Expansion of the Universe by Catherine Whiting, licensed under CC BY 4.0

3. Suppose the universe is 1D, but expanding as shown in Figure 2. Imagine 5 galaxies A-E equally spaced by 1 light year, indicated by the length of a blue box. The universe expands to double its initial size after 1 year.

   (a) **Consider being in galaxy A:**

      i. How far away is galaxy B now?

      ii. How fast has galaxy B moved in one year?

      iii. How fast has galaxy C moved away?

      iv. How fast has galaxy E moved away?

   (b) **Now consider being in galaxy C:**

      i. How fast has galaxy A moved away?

      ii. How fast has galaxy B moved away?

      iii. How fast has galaxy E moved away?

   Now consider being in galaxy D:

      i. Rank the speeds of the other galaxies from slowest to fastest.

   (c) How is what you found consistent with Hubble's Law?

   (d) Are galaxies A and E at the edge of the universe and is galaxy C at the center?

   (e) What would change if the doubling of the universe took place over 2 years?

   (f) What can be estimated about the universe using Hubble's law plot in Figure 1?

Name ____________________

1. Which of the two possible universes in Figure 1 (A or B) best represents our universe? Explain why.

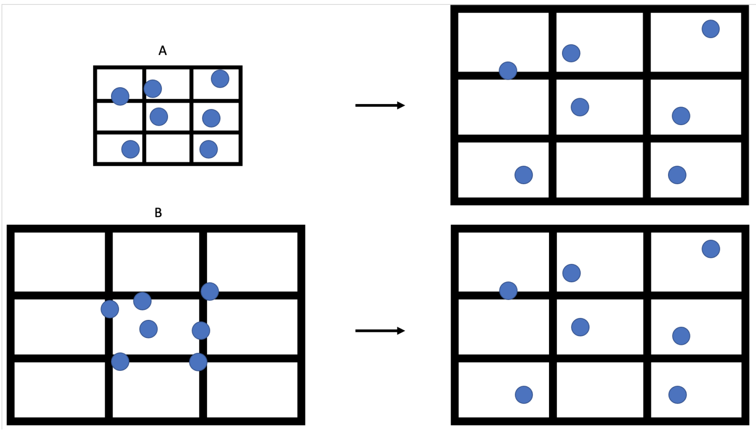

Figure 1: Expansion vs Explosion of the Universe by Catherine Whiting, licensed under CC BY 4.0

2. How did the density, pressure and temperature of the early universe compare to today?

3. What is the Big Bang theory?

4. Use the temperature data in Figure 2 to determine the approximate temperature of the universe at the following times, Also, briefly explain what was happening in the universe during that era.

- Planck Era: $10^{-45}s$
- GUT Era: $10^{-43}s$
- Electroweak Era: $10^{-38}s$
- Particle Era: $10^{-10}s$
- Era of Nucleosynthesis: $0.001s$
- Era of Nuclei: 5 min
- Era of Atoms $380,000yr$
- Era of Galaxies 1 billion yr
- Present Day 13.7 billion yr

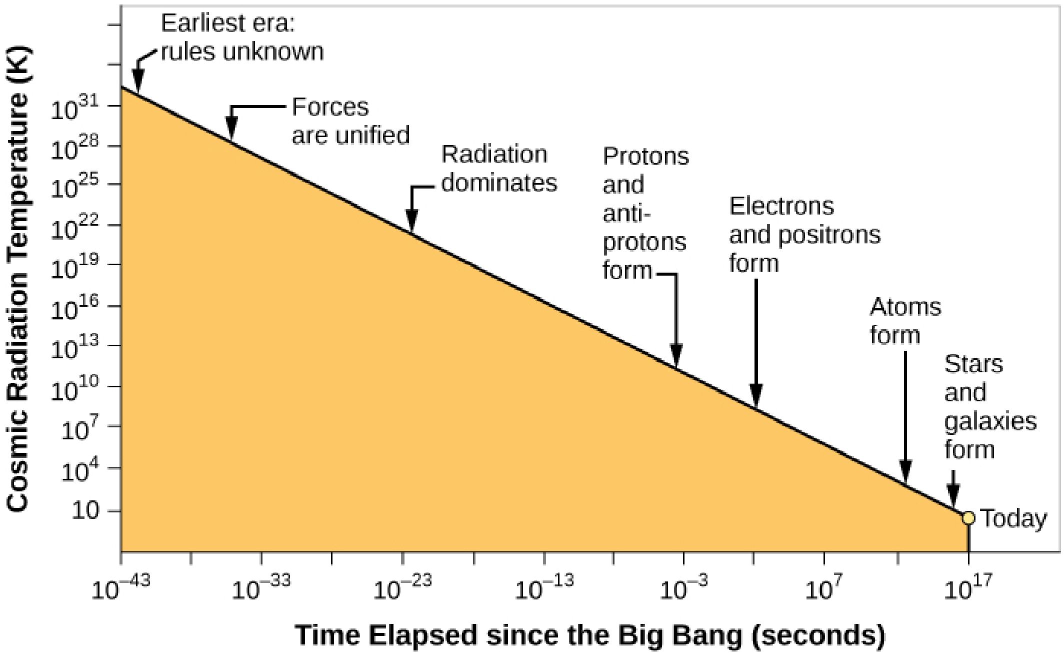

Figure 2: "Temperature of the Universe" by Andrew Fraknoi, David Morrison, and Sidney Wolff via OpenStax, licensed under CC BY 4.0

5. What was special about the time of about 380,000yr after the Big Bang?

6. What is the Cosmic Microwave Background Radiation?

7. List 2 main observational predictions that the Big Bang theory makes.

   -
   -

8. Consider each hypothetical observation below and determine whether it is consistent with the Big Bang theory. Explain your reasoning for each case.

   - A star cluster with an age of 16 billion years.
   - A galaxy at a distance of 10 billion light years with a blueshifted spectrum.
   - A galaxy at a distance of 2.5 million light years with a blueshifted spectrum.
   - A galaxy containing 90% hydrogen and 10% helium.
   - A galaxy containing 74.5% hydrogen, 24.5% helium, and 1% other heavy elements

pgfplots

Name ______________________________

1. Fill in the pie chart in Figure 1 with the correct type of matter: Dark matter, Stars, Ordinary Matter (not stars), Dark Energy

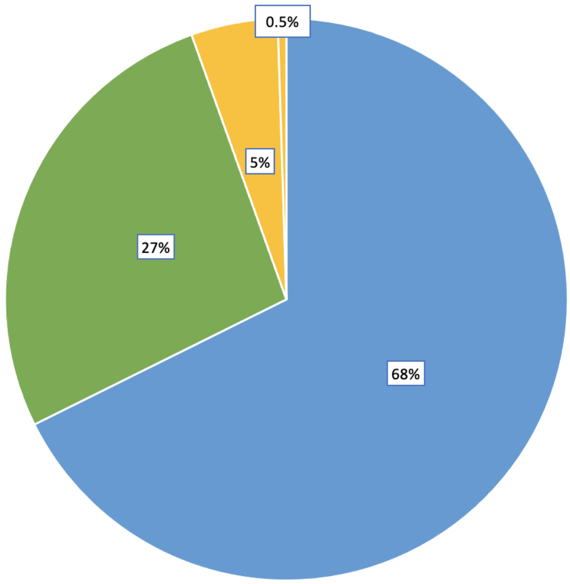

Figure 1: Mass-Energy Content of the Universe by Catherine Whiting, licensed under CC BY 4.0

2. What is dark matter? In what sense is it "dark"?

3. What is dark energy? In what sense is it "dark"?

4. In Figure 2, consider two basic types of motion: A solid disk spinning and planets orbiting the Sun according to Kepler's Laws. For each scenario, make a sketch of the orbital speed at the points A, B, C, and D and the amount of mass contained within each point's circle. Explain each rotation curve based on the matter plot you drew.

5. In Figure 3 make a sketch of the rotation curve of a galaxy that would not have any dark matter (i.e. what we would expect it to look like without dark matter). On the same plot, sketch an actual galaxy rotation curve.

6. Consider the four types of universe in Figure 4 (Recollapsing, Decelerating, Critical, Coasting, Accelerating).

   (a) Which model has the most amount of dark matter?

   (b) Which model(s) have dark energy included in the universe?

7. (a) Match the model universe number in Figure 5 to the type of universe listed in Question 6.
   - 1=
   - 2=
   - 3=
   - 4=
   - What universe does the dashed line correspond to in Figure 5?

   (b) Which type of universe predicts the oldest age for the universe? Why?

   (c) Which type of universe best represents our universe?

8. What do we think will ultimately happen to the universe, based on current data and models?

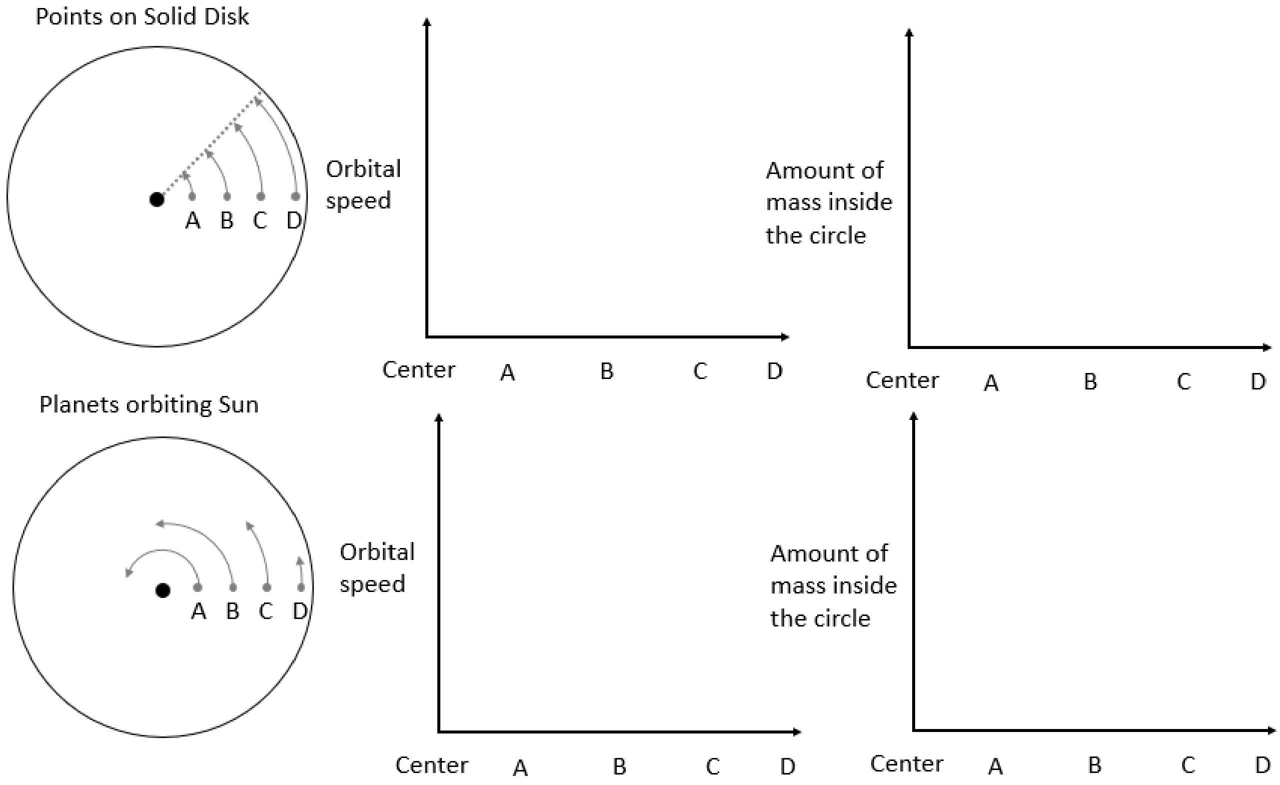

Figure 2: Types of Rotation Curves by Catherine Whiting, licensed under CC BY 4.0

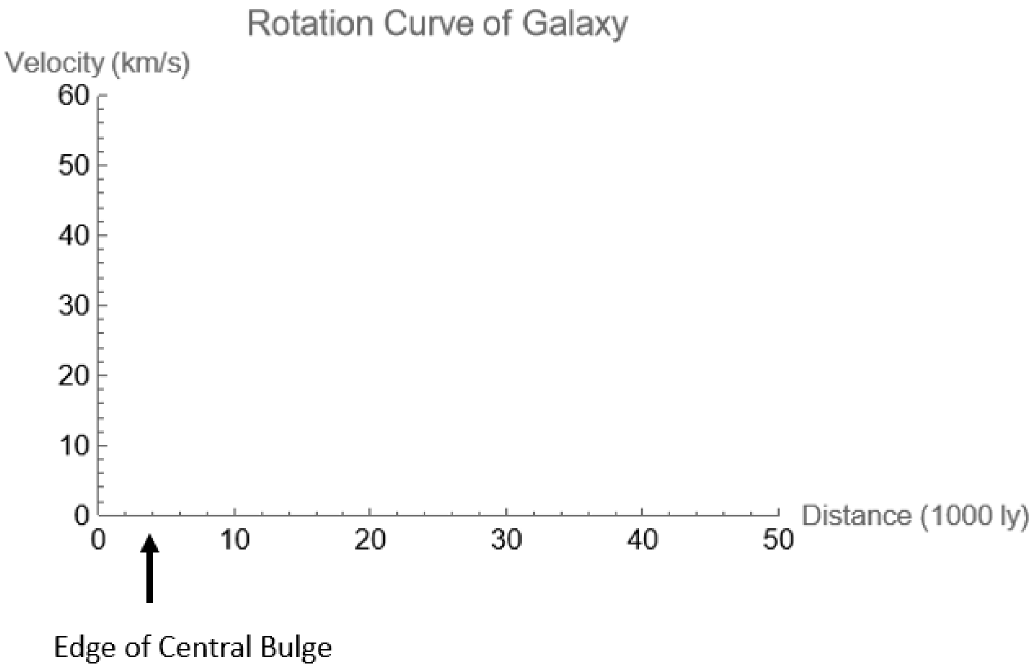

Figure 3: Rotation Curve of Galaxy by Catherine Whiting, licensed under CC BY 4.0

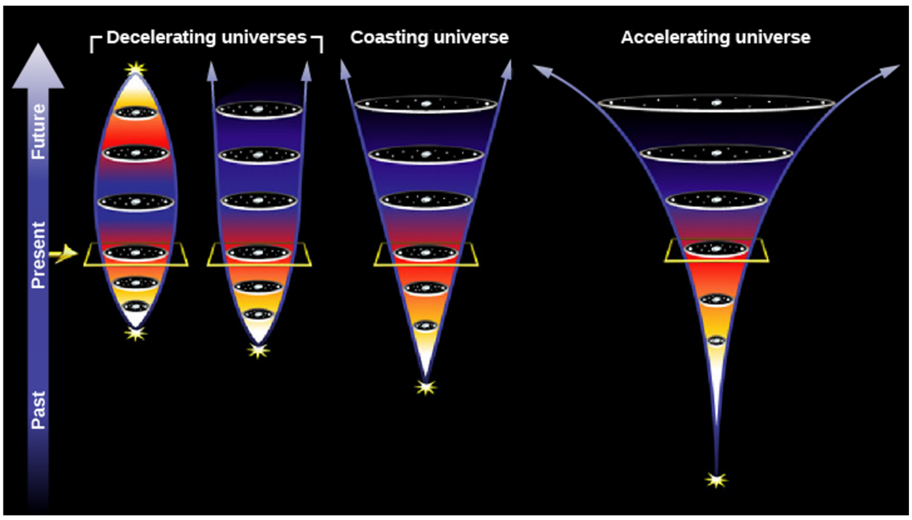

Figure 4: "Four Possible Models of the Universe." by Andrew Fraknoi, David Morrison, and Sidney Wolff via OpenStax, licensed under CC BY 4.0

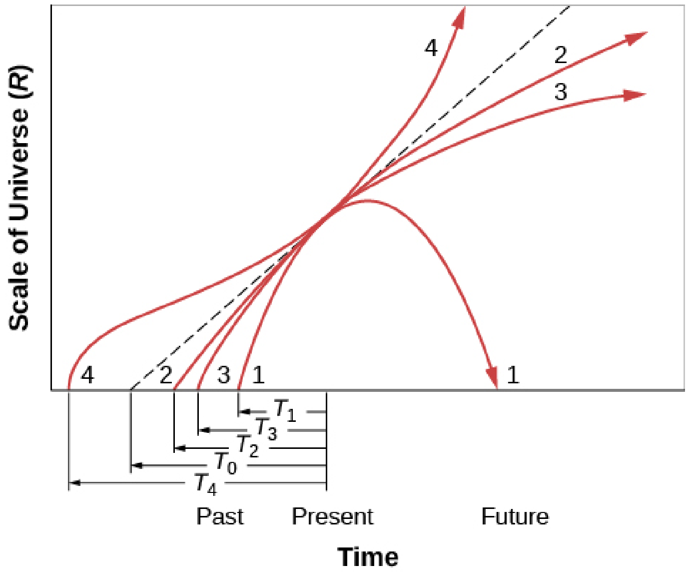

Figure 5: "Models of the Universe." by Andrew Fraknoi, David Morrison, and Sidney Wolff via OpenStax, licensed under CC BY 4.0