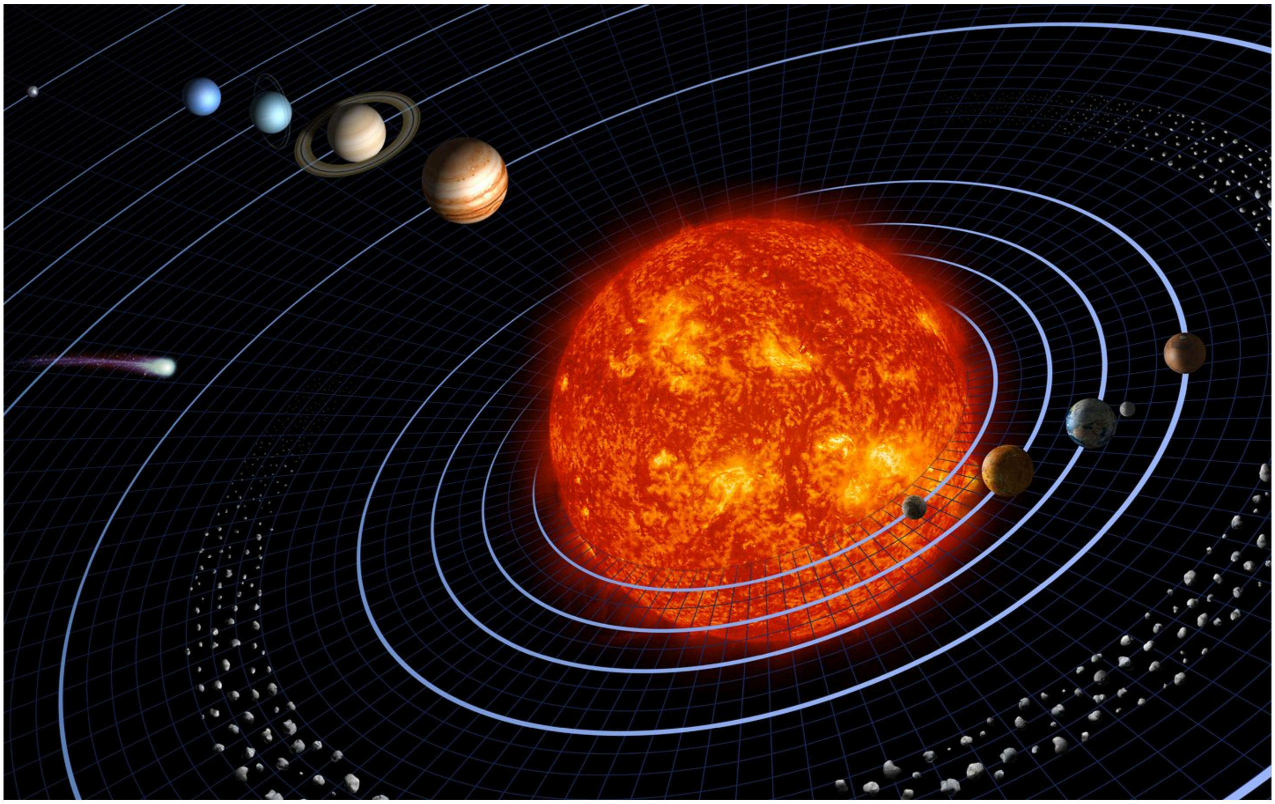
Discovering New Worlds - Student Materials

Unit 1	Earth and Space Science

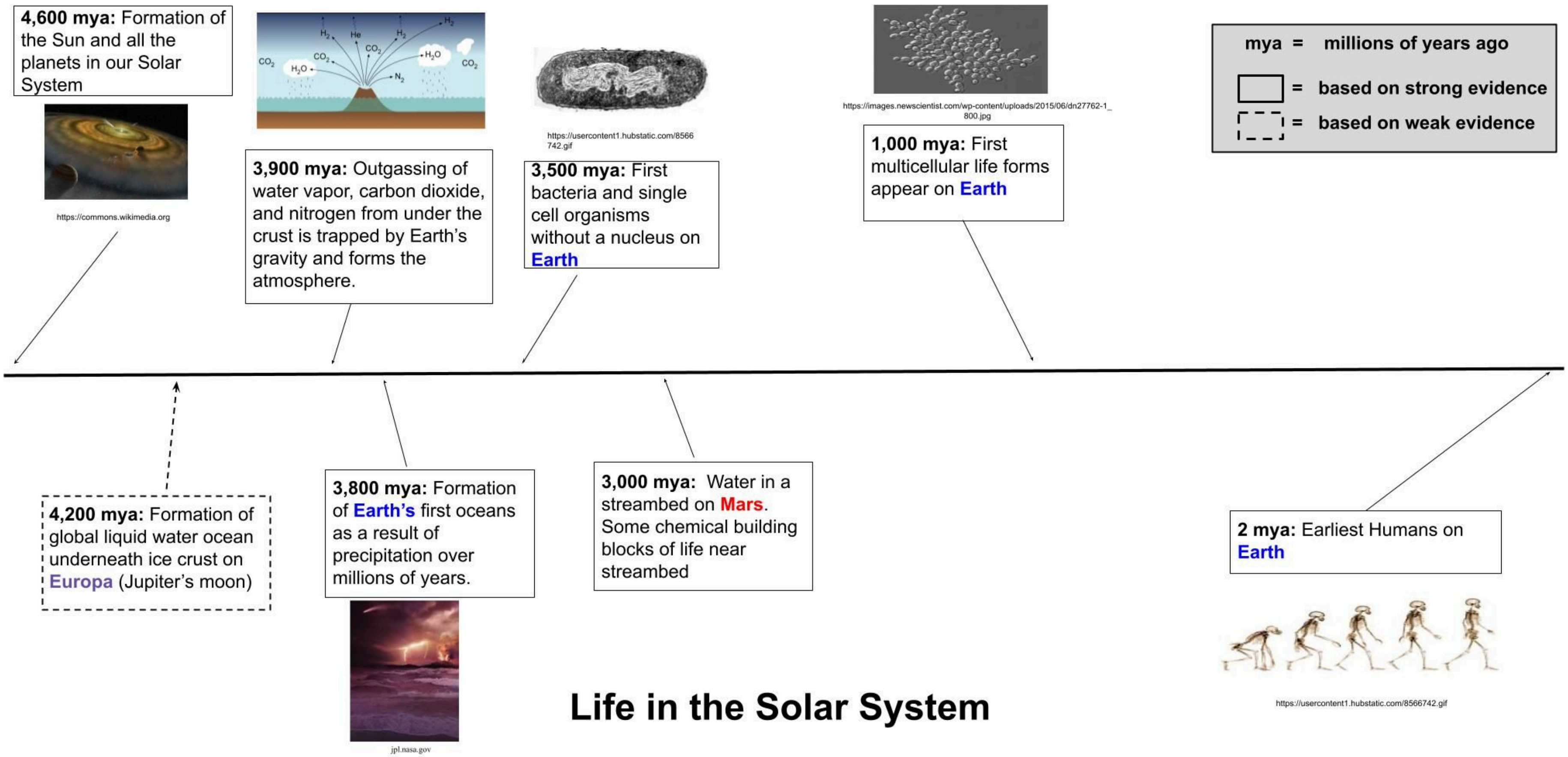


Student Materials Table of Contents

Performance Task Organizer

Unit 1 Discovering New Worlds	Earth and Space Science
Student Name:	

Life in the Solar System Timeline



Life in the Solar System Timeline

Life in the Solar System

1. Circle all the numbers and their units. Use the key at the top right of the timeline to help you determine what the numbers tell you about the event on the timeline. Write your response below.

2. Highlight the event in the timeline that is boxed with a dotted line. Use the key at the top right of the timeline to help you determine the difference between events on the timeline that are boxed with a dotted line and the events that are boxed with a solid line. Write your response below.

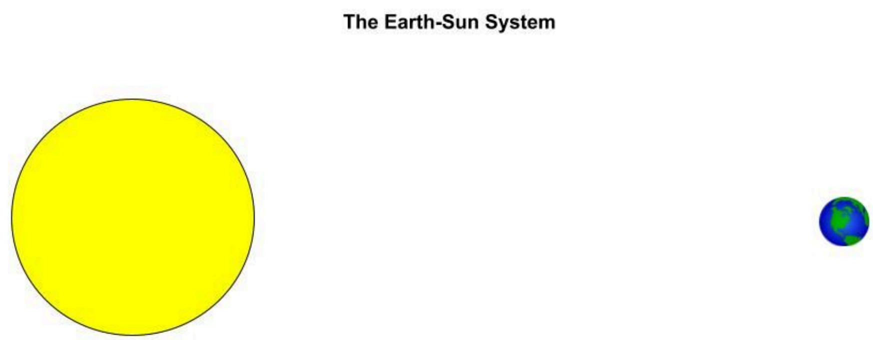
3. How long after the formation of Earth did the first life on Earth appear?

4. What are the non-living things on the timeline that might affect the existence of life on planets and other objects in our solar system?

5. What is the important story this timeline tells us about life in our solar system?

Initial Model

Why is Earth the only planet in our Solar System that has been able to sustain life? Represent your initial ideas about what makes Earth habitable in the space below.



The Earth-Sun System

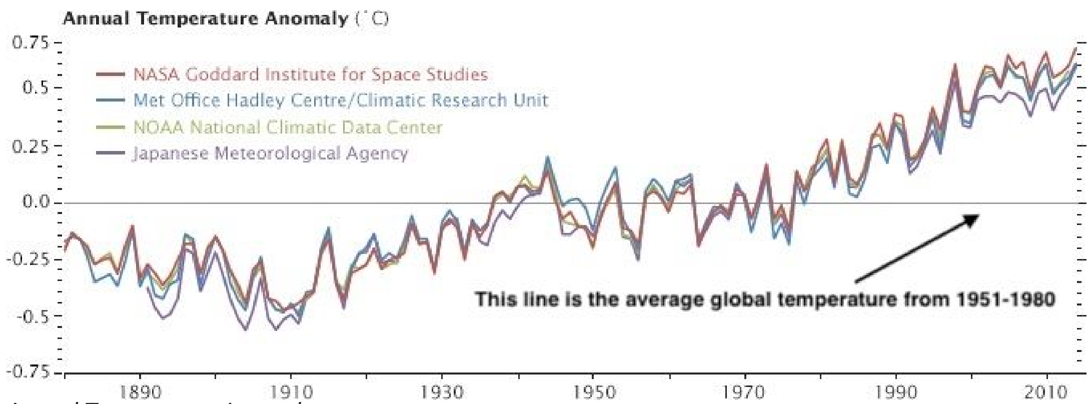
Explain your model. Describe your diagram in words as best as you can.

Tell the Story

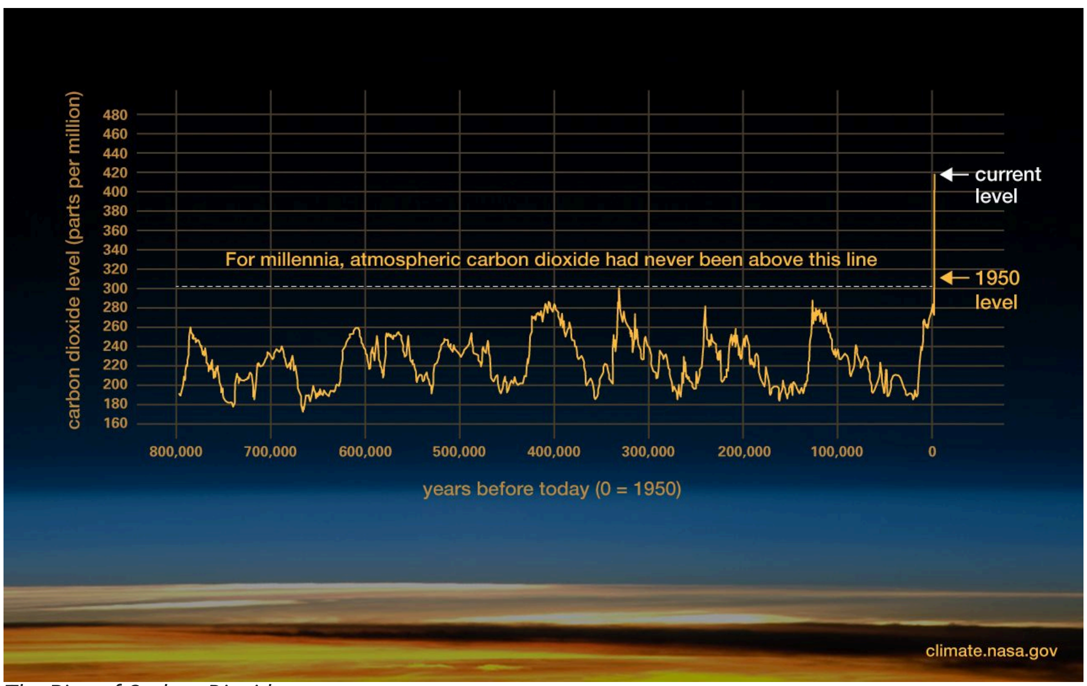
Directions:

1. **Silently read** the texts provided to you.
2. **Circle** three details that are most important to the phenomenon being described.
3. **Share** with your group. Each person should identify the details that he/she circled.
4. **Discuss** as a group, and determine the overall story. What is the phenomenon?

Text #1



Annual Temperature Anomaly



The Rise of Carbon Dioxide

Text #2

Species at Risk of Extinction

Text #3
Source: https://www.dec.ny.gov/energy/94702.html
Future Scenarios - New York

Temperature
Modeling shows that New York should anticipate more warming. Compared to the 1971-2000 period, average temperature will be

- up to 3°F warmer by the 2020s.
- up to 6°F warmer by the 2050s.
- up to 10°F warmer by the 2080s.

Precipitation
Modeling shows that New York is also likely to experience more precipitation and more variability in precipitation. Compared to the 1971-2000 period, average precipitation in New York will increase

- up to 8% by the 2020s.
- up to 12% by the 2050s.
- up to 15% by the 2080s.

Sea-level Rise, Storm Surge, and Flooding
By the 2050s, sea level is expected to be as much as 30 inches (2.5 feet) higher in New York's coastal area, as compared with sea level averaged for 2000-2004. By 2100, New York's coast could see up to 6 feet of sea-level rise. New York is very vulnerable to the impacts of sea-level rise, including storm surge and coastal flooding.

Climate Change and Health
Climate change poses a variety of health risks. Widespread impacts may occur as a result of warmer temperatures increasing pollen production in plants and ground-level ozone formation, which exacerbates asthma, allergies, and other respiratory conditions.

Changed climate conditions also look to favor the survival of insects and disease carriers such as mosquitoes and ticks, making West Nile virus, Lyme disease, and other diseases more prevalent and opening the door to new pests and diseases.

What is the overall story of what is happening to Earth?

Important details our group surfaced (provide at least 5):

1. ______________________________
2. ______________________________
3. ______________________________
4. ______________________________
5. ______________________________

Overall Story (based on group discussion):

____
____
____
____
____

Introducing the Performance Task

A rise in global average temperatures is making Earth less and less habitable!

Your task for this unit is to investigate what has made Earth the only planet in our solar system that can sustain life.

After each investigation you will consider what you have learned and decide if and how you would like to revise your initial model from page 4 of your performance task organizer.

Throughout the unit you will use your model to help you analyze and interpret data from stars and planets in other solar systems in order to write an argument from evidence about which exoplanet is most likely to be habitable. Good luck, the fate of the human species might depend on it!

How the Sun Works

What makes Earth habitable?

After discussing how you would change your initial model with your group based on what you figured out about how the Sun works, record your revised model for what makes Earth habitable. Be sure to represent your understanding of how the Sun is able to release the right amount of heat and energy for the right amount of time to support the existence of life on Earth. Consider and respond to the following reflection prompts before you revise your model and cite evidence and reasoning for any changes you made:

Reflection Prompts

1. What is the **evidence for the patterns** you identified?

2. How will those **patterns** change your model?

3. How did you use the **scale of energy and time** to figure out how the Sun works?

4. How do you think considering **scale** might be useful in thinking about other phenomena?

Revising Models Based on Evidence

1. Use the ideas captured in your responses to the reflection prompts to complete the table below and make changes to your initial model for why Earth is a planet that can sustain life.

Change to the Model	Evidence	Scientific Reasoning

2. In the space below, draw a revised version of your initial model for why Earth is a planet that can sustain life below.

Star Life Cycles

What makes Earth habitable?

After discussing how you would change your initial model with your group based on what you figured out about star life cycles, record your revised model for what makes Earth habitable. Be sure to represent your understanding of how the Sun is able to release the right amount of heat and energy for the right amount of time to support the existence of life on Earth. Consider and respond to the following reflection prompts before you revise your model and cite evidence and reasoning for any changes you made:

Reflection Prompts

1. Why was understanding *stability and change* of stars useful in revising your model? Why might it be useful to understand *stability and change* when investigating other phenomena?

2. How did studying stars at different *scales* of our galaxy (solar system, supercluster, atomic) support you in revising your model?

Revising Models Based on Evidence

1. Use the ideas captured in your responses to the reflection prompts to complete the table below and make changes to your model for why Earth is a planet that can sustain life.

Change to the Model	Evidence	Scientific Reasoning

2. In the space below, draw a revised version of your model for why Earth is a planet that can sustain life below.

Which star(s) are likely to have a nearby Earth-like planet?

1. Use a blank circle to record the data for each star in this data set. Place them all on the star chart to compare them to our Sun.
2. Use the star chart to make a claim about the color and the expected lifespan of each star based on where you placed it on the chart.
3. Decide based on the data whether you think it is possible that the star could have a nearby habitable planet.

Star Name	**Luminosity** (L_{Sun})	**Temperature** (Kelvin)	**Color**	**Expected Life Span** (years)	**Could this star support a habitable planet?**
Kepler-79	.93	6,174			• Yes • Maybe • No
Kepler-442	.117	4,402			• Yes • Maybe • No
Kepler-432	9.206	4,995			• Yes • Maybe • No
Gliese 440	0.0005	8,500			• Yes • Maybe • No
Kepler-18	2.69	5,345			• Yes • Maybe • No
Eta Carinae	5,000,000	40,000			• Yes • Maybe • No
Kepler 186	.055	3,755			• Yes • Maybe • No
Trappist 1	0.0005	2,511			• Yes • Maybe • No
HD 20782	7.38	5,578			• Yes • Maybe • No
TOI-2257	.06	3446			• Yes • Maybe • No

Which star is most likely to have a nearby Earth-like planet?

Review the star data you analyzed on the previous page. Of all the stars on that list, select one star you think is most likely to have a nearby planet that could be habitable the way that Earth is. Then record your argument for why you think that star is the best choice.

Claim	
The star that is the most likely to have a nearby Earth-like planet is...	
Evidence	**Reasoning**
The data I was given on the star was...	The data and information I figured out about this star supports my claim because…
Based on this data, I figured out that the star...	My model also helps justify my claim because...

Reflection prompt 1: How does the concept of *stability and change* help support your argument?

Reflection prompt 2: How did studying stars at different *scales* (solar system, supercluster, atomic) support your argument?

Connect to the Performance Task: Planets and Orbits

What makes Earth habitable?

After discussing how you would change your model with your group based on what you figured out about planets and orbits, record your revised model for what makes Earth habitable. Be sure to represent your understanding of the features of the motions of orbiting objects that lead to stability in temperature that can support the existence of life on Earth. Consider and respond to the following reflection prompt before you revise your model and cite evidence and reasoning for any changes you made:

Reflection Prompts

1. How was creating mathematical representations from data, like graphs and equations, useful in revising your model? Why might creating mathematical representations from data, like graphs and algebraic equations, be useful when developing a model for other phenomena?

Revising Models Based on Evidence

1. Use the ideas captured in your responses to the reflection prompts to complete the table below and make changes to your model for why Earth is a planet that can sustain life.

Change to the Model	Evidence	Scientific Reasoning

2. In the space below, draw a revised version of your model for why Earth is a planet that can sustain life below.

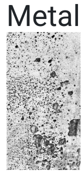
After going back and adding to/revising your model for what makes Earth habitable, analyze the data in the table below to decide which of these planets could be habitable. Use information from the *Solar System Data* and *Materials in Our Solar System* tables on the following page to support your claim about whether each planet is terrestrial or jovian.

Exoplanet Name	**Does the planet stay within the habitable zone?**	**Equatorial Diameter** (km)	**Mass** (Earth = 1)	**Density** (g/cm^3)	**Is the planet terrestrial or jovian?**	**Could this planet be habitable?**
Kepler 79 b		43,345	10.90	1.43		• Yes • Maybe • No
Kepler 18 b		24,889	6.99	4.90		• Yes • Maybe • No
Kepler 186 f		14,908	1.17	unknown		• Yes • Maybe • No
Kepler 442 b		17,073.53	2.3	7.46		• Yes • Maybe • No
TOI-2257 b		127955.91	5.45	unknown		• Yes • Maybe • No
HD 20782 b		unknown	unknown	unknown		• Yes • Maybe • No
Trappist 1 f		13315.39	1.04	5.09		• Yes • Maybe • No
Trappist 1 g		14360.18	1.32	5.04		• Yes • Maybe • No

Solar System Data

Celestial Object	Equatorial Diameter	Mass	Density	Terrestrial or Jovian?
Mercury	4,879	.06	5.4	terrestrial
Venus	12,104	.82	5.2	terrestrial
Earth	12,756	1	5.5	terrestrial
Mars	6,794	.11	3.9	terrestrial
Jupiter	142,984	317.83	1.3	jovian
Saturn	120,536	95.16	.7	jovian
Uranus	51,118	14.54	1.3	jovian
Neptune	49,528	17.	1.8	jovian

Materials in Our Solar System

Substance	Examples	Density
Hydrogen and Helium Gas 	hydrogen, helium	.1 to .2 g/cm^3 (gas state)
Hydrogen Compounds 	water (H_2O) methane (CH_4) ammonia (NH_4)	.5 to 1 g/cm^3 (solid state)
Rock 	various minerals	2.2 to 3.4 g/cm^3 (solid state)
Metal 	iron, nickel, aluminum	7.9 to 8.9 g/cm^3 (solid state)

Which exoplanet is most Earth-like? CER

Review the exoplanet data you analyzed on the previous page. Of all the exoplanets on that list, select one star you think is most likely to be a planet that is habitable the way that Earth is. Then record your argument for why you think that exoplanet is the best choice.

Claim	
The exoplanet that is the most Earth-like is…	
Evidence	**Reasoning**
The data I was given on the exoplanet was... Based on this data, I figured out that the exoplanet...	The data and information I figured out about this exoplanet supports my claim because… My model also helps justify my claim because...

1. How was creating mathematical representations from data, like graphs and algebraic equations, useful in developing your argument?

2. During the unit we learned that an argument has at least two valid evidence-based claims. Strengthen your argument by explaining why the claim you made is stronger than another potential claim.

Directions:

Use all of your resources from the unit (Performance Task Organizer, class notes, handouts) to respond to the following reflection prompts.

Part 1: Arguing from Evidence

1. How would you describe arguing from evidence? How has your thinking changed since the beginning of the unit?
2. Describe how a peer or activity from the unit changed your thinking on what arguing from evidence is and how it can be used.
3. What questions do you still have about arguing from evidence?

Part 2: Final Performance Task Argument

1. There was more than one exoplanet in the data set that could potentially be habitable, how did you decide which exoplanet to write an argument about?
2. When writing your final argument, you considered data from exoplanets and their stars, how did you decide what counted as evidence? Discuss your decision making process, giving specific examples from your argument.
3. How could you improve your final argument?

How the Sun Works 5E

Unit 1 Discovering New Worlds	Earth and Space Science
Student Name:	

How Does the Sun Provide Energy

How has the Sun provided Earth with the “right” amount of energy for such a long time?

Phenomenon: Our Sun releases 2.41 X 10^{30} Mega Electron Volts of energy per second, or 2,410,000,000,000,000,000,000,000,000,000 Mega Electron Volts of energy per second. That’s more energy than the entire world uses in a whole day!

Directions:
- Consider what you know about our Sun and ways that energy is released
- Brainstorm 2-5 ideas for how the Sun is able to provide such a tremendous amount of energy in the left column below.
- Explain your thinking in the column on the right.

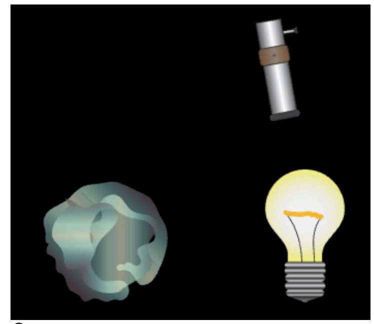
What are your ideas for how the Sun provides so much energy?	What did you observe in the video or in your life that made you think this?

Investigating Light from the Sun

Part 1: What does a spectrometer tell us about light?

To better understand light, scientists view light through an instrument called a spectroscopy telescope. The spectroscopy telescope allows us to see all the different types of light the source is releasing. Using the Three Views Spectrum Demonstrator Simulation , you will figure out how a spectroscopy telescope can be used to investigate light from different sources, including the Sun.

1. Point the spectroscopy telescope directly at the light bulb and record your observations from the "spectrometer."



Spectrometer

2. Explain your observations: what do you think happened to the light from the lightbulb as it passed through the spectroscopy telescope?

3. Point the spectroscopy telescope at the light bulb from the left side of the gas cloud and record your observations from the spectrometer below:

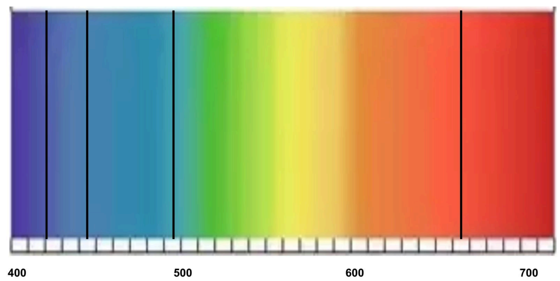
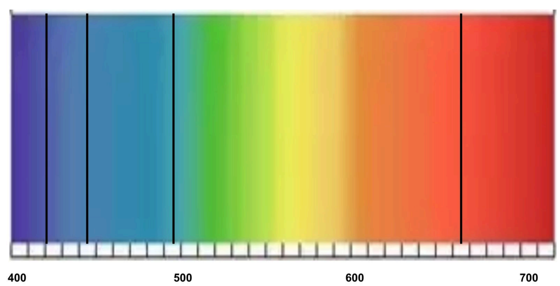
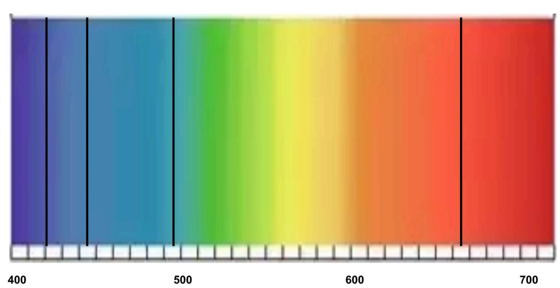
4. Explain your observations: what do you think happened to the light from the lightbulb as it passed through the gas cloud before passing through the spectroscopy telescope?

Part 2: What do we see when we observe the Sun with a spectrometer?

The Sun is made of gases. Just like in the simulation, light released from inside the Sun has to pass through the gases that make up the Sun. In this part of the investigation you will determine the pattern in the light from the Sun.

Astronomers used a spectroscopy telescope to collect data while observing the Sun on several occasions. Using the table below, answer questions about the Sun.

Spectra from the Sun

Observation	Spectrum
1	
2	
3	

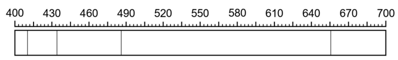
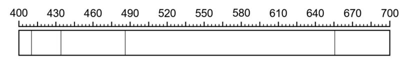
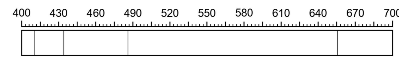
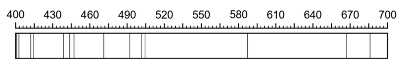
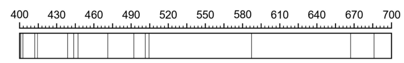
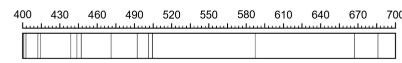
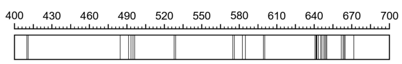
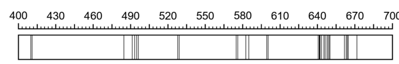
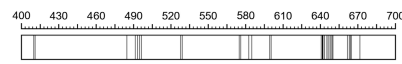
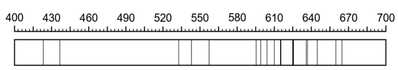
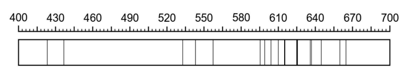
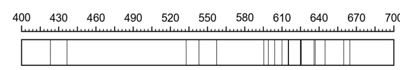
1. What pattern do you notice in the sunlight data across the 3 observations? Describe the *evidence* for the pattern.

2. What do you think *caused* the pattern you observe?

Part 3: How does the Sun's spectrum compare to the spectra from light passed through gases in a lab?

The spectra data below were collected in a laboratory when light was passed through several samples of each isolated gases listed. We can compare these spectra from the lab to the Sun's spectrum to figure out which gas(es) the Sun is composed of.

Spectra of Elements Observed in a Lab

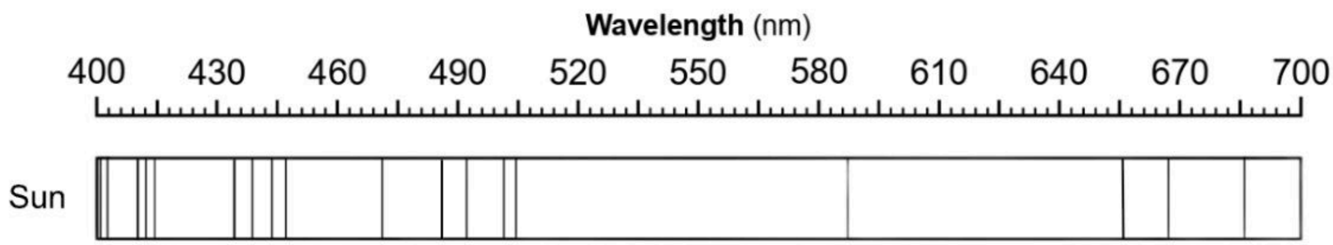
Gas	Sample 1	Sample 2	Sample 3
Hydrogen			
Helium			
Nitrogen			
Oxygen			

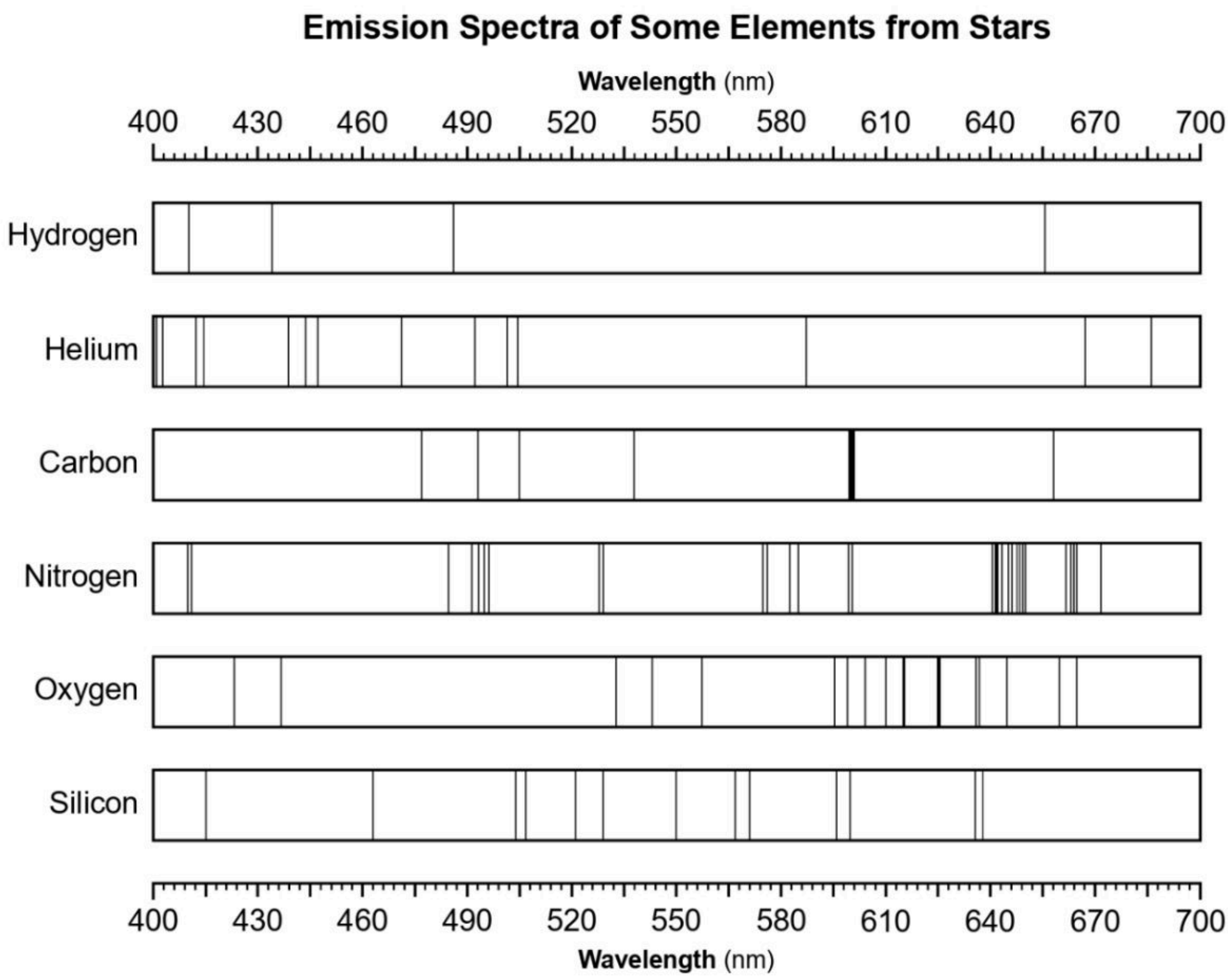
See-Think-Wonder
Directions: Refer to the table of spectra above to complete the organizer.

See **What pattern did you observe in the data?**	**Think** **What could this pattern mean?**	**Wonder** **What questions do you have about this pattern?**

Compare the spectrum from the Sun to the spectra of the various elements tested in the lab. What connections can you make between them? (In other words, what pattern do you notice?) What does this make you think about which elements might be present inside the Sun?

Spectra of Sun and Elements from the Lab





Determining the Composition of the Sun

What is the composition of the Sun? How do you know?

Make a scientific claim about which gas or gases the Sun is composed of based on your data from the Explore phase and your understanding of how light behaves when it passes through gases.

Claim	Evidence	Reasoning
Our Sun is composed of. . .	My evidence for this is. . .	The scientific concept that links my evidence to my claim is. . .

Summary Task

Today we completed the first class consensus discussion of the unit! How did it go?

1. One thing that went well in the discussion:

2. One thing we can improve the next time we have a discussion:

3. One person who helped me learn today:

What did you learn from this person?

4. One idea that I contributed to my group or my class:

Explain what you know about the following questions, based on what we discussed today:

1. How did you identify the spectra *patterns* that helped you figure out the composition of the Sun?

2. If someone claimed that there are no *patterns* in the spectra of the Sun and in the spectra of each of the gases, what could you say to convince them there are patterns?

3. Read the two statements below and circle the statement that is a good example of a pattern.

Statement 1: A pattern I have noticed is that female students perform better than male students in science classes at my school.

Statement 2: Female students at my school have an average grade of 86.7% in science classes, while male students have an average grade of 82.5% in science classes. There seems to be a pattern of female students performing better than male students in science classes at my school.

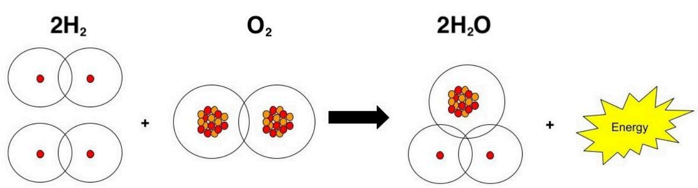
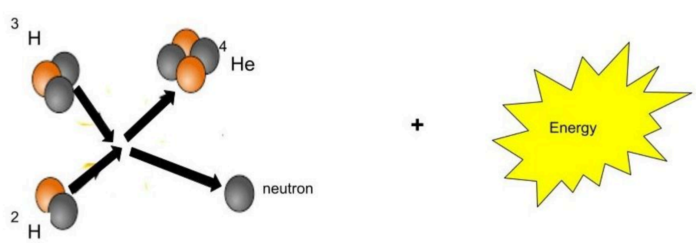
Explain your thinking:

Our Sun: Chemical or Nuclear Energy?

Scientists have observed that our Sun releases 2.41 x 10^{30} Mega Electron Volts of energy per second (MeV/s), or 2,410,000,000,000,000,000,000,000,000,000 MeV/s. That's more energy than the entire world uses in a whole day! We also know from the composition and age of sedimentary rocks of marine origin that oceans were present on Earth's surface nearly 4 billion years ago, so the Sun has been providing the right amount of energy for liquid water to exist on Earth for at least that long. But how is it possible that our Sun has released such a huge amount of energy for such a long time?

Analyze and interpret the data in the table below. Find evidence that supports a claim about which process can be responsible for releasing all the energy coming from the Sun.

Possible Energy-Releasing Processes in the Sun

Type of reaction	Equation	Energy released by one reaction	Estimated amount of time the Sun would be able to release energy at rate of $2.41x10^{30}$ MeV/s
Chemical		.0000005930 MeV	50,000 years
Nuclear		17.6 MeV	10 billion years

What's the Evidence?

The Claim and Data cards contain information from the data table above. Discuss the evidence on each card, then determine which of the two claims the evidence supports. Use the reasoning provided on some of the cards to help you make sense of the evidence, and add your own reasoning to the cards with blank lines.

Constructing an Evidence-Based Argument

Use the scaffold below to critique the two possible claims and to construct the strongest argument based on the evidence.

Investigation Question: ***Is our Sun releasing energy due to chemical or nuclear reactions?***

Possible Claim #1 The Sun is releasing energy due to. . .	**Possible Claim #2** The Sun is releasing energy due to. . .
Evidence for Claim #1 The evidence that supports this claim is . . .	**Evidence for Claim #2** The evidence that supports this claim is . . .
Evaluation and Critique Use your science knowledge to critique claim #1 by considering the quality and strength of the evidence.	**Evaluation and Critique** Use your science knowledge to critique claim #2 by considering the quality and strength of the evidence.

Decide which claim you think is best supported. Write a scientific argument that includes the following:

- the investigation question;
- the claim you think is best-supported by the evidence;
- a summary of the evidence that supports your claim;
- the critique of your claim compared to the other claim based on the evaluation of the evidence.

What will happen to our Sun in the future?

Now that your class has determined how the Sun releases tremendous amounts of energy, you can make some predictions about the Sun's future. Refer to the equation for nuclear fusion.

Nuclear Fusion Equation

hydrogen + hydrogen → helium + energy

1. What do you predict will happen to the amount of hydrogen over time? Use evidence from the equation above to justify your claim.

2. What do you predict will happen to the amount of helium over time? Use evidence from the equation above to justify your claim.

3. Based on your answers to #1 and #2, do you predict our Sun will provide Earth with the right amount of energy forever?

How the Sun Works Model Rubric

How the Sun Works	Proficient	Developing
Model based on How the Sun Works	The model effectively and accurately shows what is happening within the Sun to produce energy and includes all of the components below: • Hydrogen and helium modeled as particles. • Representation of nuclear fusion within the Sun's core. • Energy released through nuclear fusion modeled as radiating in all directions, including towards Earth. (This may be shown with arrows or squiggly lines, for example.) The components of the model "speak for themselves" for the most part. **OR** There are legends, keys, or written captions to clarify the components.	The model is incomplete in showing what is happening within the Sun to produce energy, **missing one or more** of the components below: • Hydrogen and helium modeled as particles. • Representation of nuclear fusion within the Sun's core. • Energy released through nuclear fusion modeled as radiating in all directions, including towards Earth. (This may be shown with arrows or squiggly lines, for example.) The components of the model do not really "speak for themselves." **OR** Legends, keys, or written components are insufficient to clarify the model.
Empirical Evidence of Patterns	Empirical evidence is cited for any patterns used as evidence to revise the model. Response to reflection prompt 1 clearly articulates that evidence must be cited to confirm a pattern.	Patterns are used as evidence to revise the model, but empirical evidence for the patterns is not cited. Response to reflection prompt 1 does not clearly articulate that evidence must be cited to confirm a pattern.
Scale of Time in How the Sun Works	Either the model or a written explanation shows the relevance of the scale of energy produced by chemical and nuclear reactions vs the scale of energy produced by the Sun in determining what process is generating energy within the Sun. Either the model or a written explanation shows the relevance of scale of time: the length of time that the Sun has been releasing the right amount of energy for liquid water to exist on Earth is sufficient time for life to evolve. Response to reflection prompt 2 clearly articulates how considering scale might be useful in thinking about other phenomena.	There is little or no consideration of the scale of energy in the model or in the accompanying explanation. There is little or no consideration of the scale of time needed for life to evolve on Earth in the model or in the accompanying explanation. Response to reflection prompt 2 does not clearly articulate how considering scale might be useful in thinking about other phenomena.
Student Self- Score	**Circle One** **Proficient** **Developing**	**Glow**: **Grow**:

Teacher/Peer Score	Circle One Proficient Developing	**Glow**: **Grow**:

Relevance to your life: Think about everything that you have learned throughout this unit so far.

1. What is one idea and/or skill you learned that you think is important to teach someone in your family or community?

2. To whom do you intend to teach this idea and/or skill? Why do you think it is important for this person to learn this idea and/or skill?

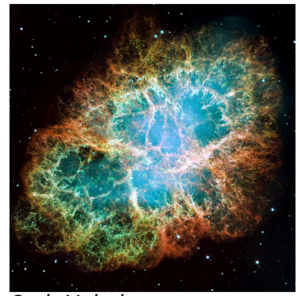
Star Life Cycles 5E

Unit 1 Discovering New Worlds	Earth and Space Science
Student Name:	

What Was Supernova 1054?

Individually review the following sources, then answer the questions below:

- The text July 4, 1054
- The image called Crab Nebula
- The video of Supernova 1054



Crab Nebula

1. Based on the accounts provided by the Chinese, Arab, and Native American observers, what is a supernova?

2. How many days was Supernova 1054 visible in the sky?

3. How would you describe the Crab Nebula remnants of Supernova 1054?

4. What are your observations from the Supernova 1054 video?

Discuss with your group:

What is the overall story about Supernova 1054?

In the beginning. . .	Then. . .	Now. . .

5. What are your initial ideas about what caused the changes in the star that you just observed in the visualization?

6. What questions would you want to investigate further in order to help you determine what kind of star can support an Earth-like planet?

July 4, 1054: Crab Nebula Makes a Spectacular Debut in the Heavens

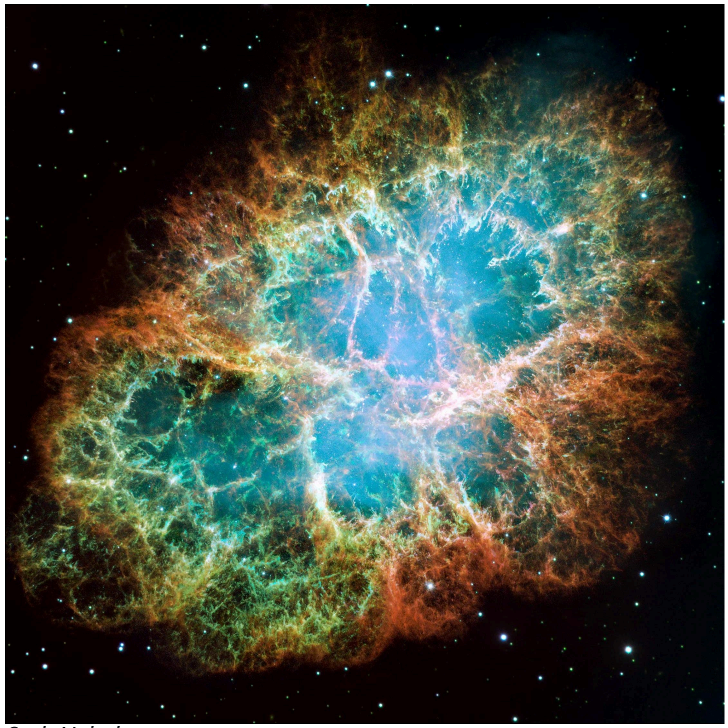
Chinese astronomers mark the beginning of Supernova 1054, heralding the birth of what will become known as the Crab Nebula.

1054: A supernova noted by Chinese observers heralds the creation of the Crab Nebula. The exact date has been disputed, but most accounts accept the Chinese date of July 4.

Supernova 1054, as it is now known, was spotted in the constellation Taurus by Chinese astronomers, who recorded no fewer than 75 supernovas (or "guest stars," as they called them) between 532 B.C. and A.D. 1064. In this case, however, the magnitude was unusually large: The star shone roughly four times brighter than Venus and was visible in daylight for 23 days.

It remained visible in the night sky for 653 days.

The remnant of that exploding star is what we now know as the Crab Nebula. The nebula itself wasn't officially recorded until 1731 by English astronomer John Bevis.



Crab Nebula

The Chinese weren't the only ones to make an early sighting: Astronomers in the Arab world provided their own accounts, and archeological evidence found in North America suggests that native american sky watchers also recorded the supernova.

What Kinds of Stars Have Long and Stable Life Spans?

The Sun has been providing the Earth with energy for 5 billion years and it is expected to keep doing so for another 5 billion years. Other stars also exist for very long periods of time compared to how long humans have been around, making it impossible for humans to observe star lifespans. Scientists have been able to collect data from millions of stars in the universe that vary in age and have different properties. By programming this data into a computational model, we can simulate the life span of many different stars. This investigation uses a computational model called *Star in a Box*, which allows us to make predictions about how different stars change over time.

This simulation allows us to observe changes in size, temperature, brightness, and mass throughout the lifespan of a star. The goal of using this simulation is to help you understand the fate of stars based on their initial masses. More specifically, by the end of this activity you should be able to identify patterns in the relationship between a star's mass and how it changes over time.

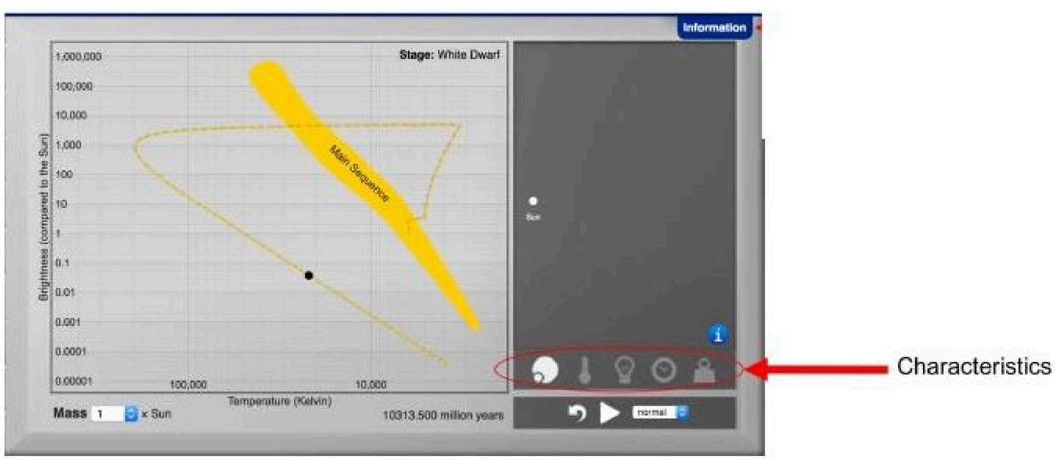
Before you begin the investigation, read over the user guide for *Star in a Box*. Be sure to ask your classmates or your teacher if you have any questions about how the simulator works.

Star in Box User Guide:

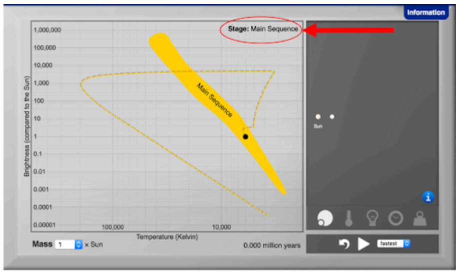
- Open your internet browser and search for Star in a Box Simulation
- Open the lid of your Star in a Box.

The graph shows a star's luminosity (rate of energy release) plotted against its temperature. On the right panel, you have data about five characteristics of your star: (1) size and color, (2) temperature, (3) luminosity, (4) time per stage, and (5) mass.

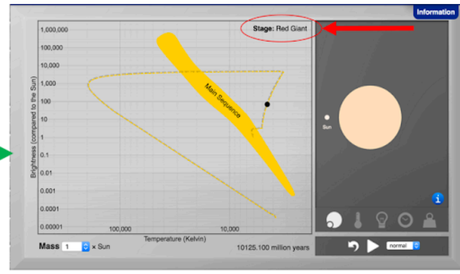
Based on the class questions, which data are the focus for this activity?



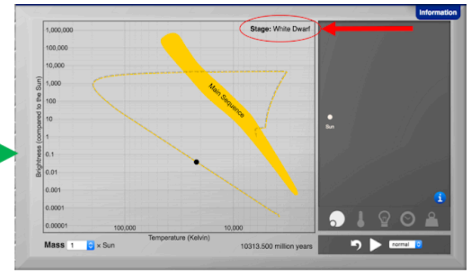
The name of the current stage of the star is in the upper right corner of the diagram. All stars begin in the Main Sequence stage. After you press "play" the star characteristics change so its place on the graph changes. Different places on the graph correspond to different stages of a star's life cycle. Here is an example of the three stages a star like the Sun goes through:



Stage: Main Sequence

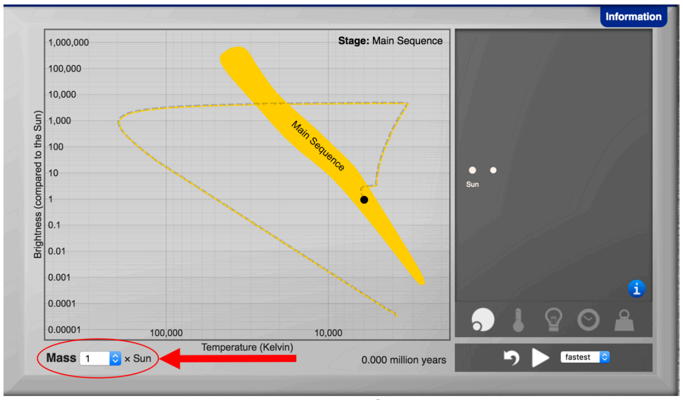


Stage: Red Giant



Stage: White Dwarf

When you open the lid, the default star has the same mass of the Sun, so you can consider this star to be our Sun or to be very similar to our Sun. You can change the mass, and select stars whose masses range from one fifth of the mass of the Sun to stars with a mass 40 times larger than the mass of the Sun!



Group the Stars Based on Life Cycle

Run the simulation on "fast" for stars of all solar masses in the simulation. Indicate below how you would group the stars based on the stages they go through.

Group	Group 1 (our Sun and stars like our Sun)	Group 2	Group 3
Stages of Life Cycle	1. Main Sequence 2. Red Giant 3. White Dwarf		
Group Which masses fall in this group?			

Group 1: Our Sun and Stars with Comparable Mass
Set the simulation to 1 solar mass. Observe how our Sun and stars with comparable masses are likely to change during the different stages of their life cycles.

Stage	Main Sequence	Red Giant	White Dwarf
Time in this stage			
Change in size			
Change in temperature			
Change in luminosity			
Change in mass			

Group 2: ________________________

Set the simulation to one of the group 2 masses and run it so that you can observe stars in this group are likely to change during the different stages of their life cycles.

Stage			
Time in this stage			
Change in size			
Change in temperature			
Change in luminosity			
Change in mass			

Group 3: ______________________

Set the simulation to one of the group 3 masses and run it so that you can observe stars in this group are likely to change during the different stages of their life cycles.

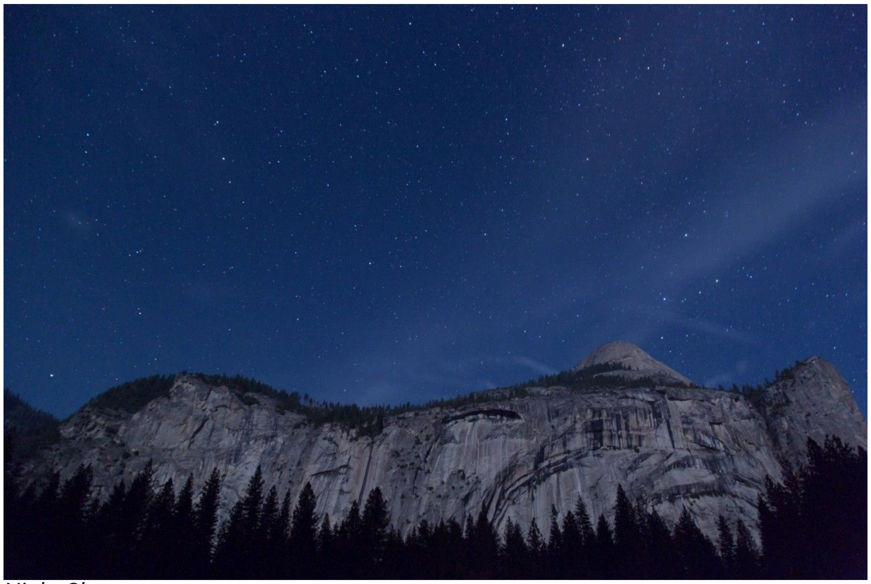
Stage				
Time in this stage				
Change in size				
Change in temperature				
Change in luminosity				
Change in mass				

See-Think-Wonder

See What pattern did you observe in the data?	**Think** What do you think this pattern means?	**Wonder** What questions do you have about the pattern?

What Properties of Stars Give Us Clues About Their Life Spans?

Have you ever seen stars in the night sky? If you live in the city, you may see fewer stars than in the image below. From a dark place on Earth, many stars are visible.



Night Sky

1. What do you think we would see if we looked at that same portion of the sky with an even more powerful telescope?

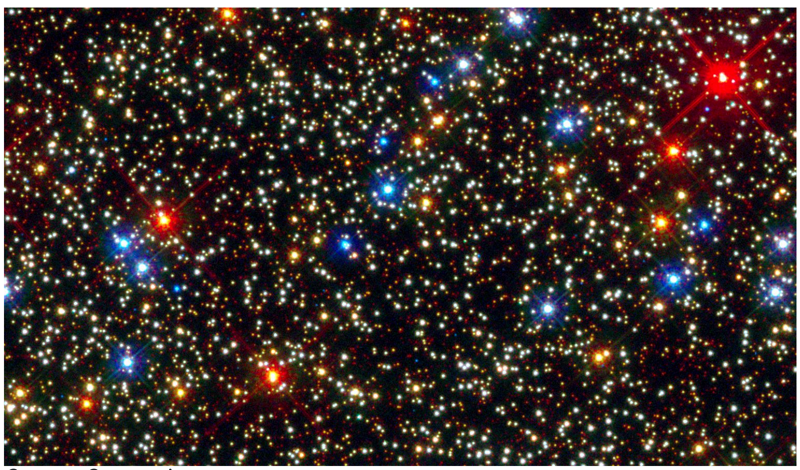
2. What do you think we would see if we looked at the stars with a telescope that is in space?

The Hubble Telescope

Hubble Telescope

In 1990, NASA launched the powerful Hubble telescope into space. Since then it has recorded images and collected data, revolutionizing our understanding of stars and space.

The image below is of the heart of a giant star cluster known as Omega Centauri. A collection of nearly 10 million stars in all, it's the largest of about 150 star clusters in the Milky Way.

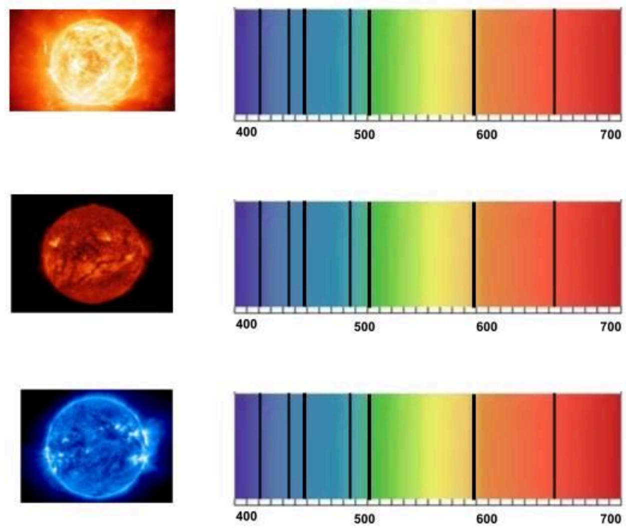


Omega Centauri

Examine the image and light spectra of several stars in the cluster closely, then respond to the questions that follow.

1. What do you observe about the stars in the Hubble image?

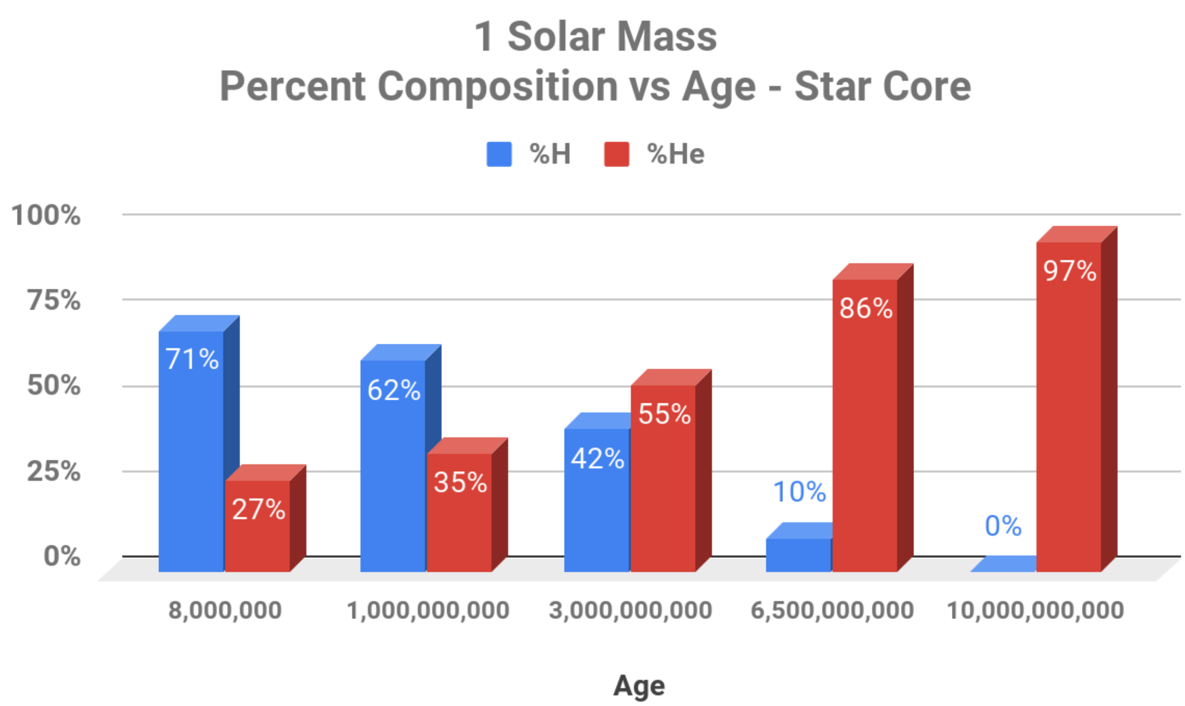
Spectra Data from Omega Centauri Star Cluster



2. What do you observe in the star light spectra from stars in the Hubble image? Explain your observations.

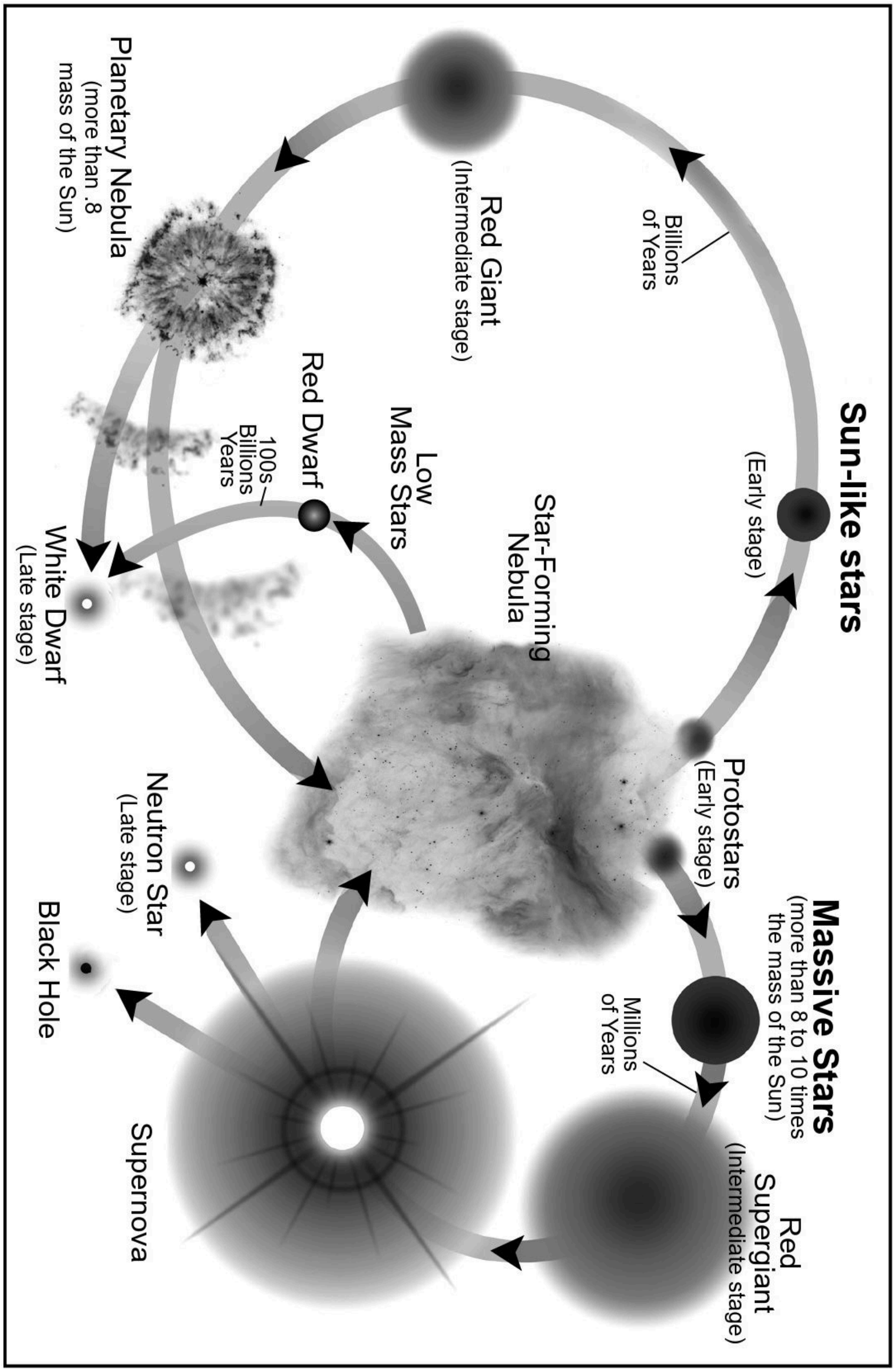
3. What do you think explains the differences observed in the stars, given your observations about the spectra?

Composition of 1 Solar Mass Star



Star Life Cycles Optional Extension

The life cycles of stars can be modeled in many ways. In the previous activity, you used a digital model to view how stars of different masses change over time. These changes can also be viewed as in a model like the one shown in the *Life Cycles of Stars Model* below.



Use the three-level guide and the Star in a Box simulation to annotate and interpret the *Life Cycles of Stars Model*

Step 1 - Reading the Lines

1. What types of stars does this model include?

2. On the model, identify the three paths a star can take, and mark them in different colors. Number the paths 1-3 and describe the phases a star moves through for each one below:

Path 1:

Path 2:

Path 3:

3. Using the model, rank each path a star can take from fastest to slowest

Speed	Path Number	Number of years
fastest		
medium		
slowest		

Step 2 - Reading Between the Lines
Compare the diagram to the Star in a Box Simulation to respond to each prompt below.

1. On the model, annotate where the "main sequence" is for each star type.
2. On the model, annotate the masses of the stars from the star in a box that took each path
3. Use the Star in a Box Simulation and the *Life Cycles of Stars Model* to predict the behavior of stars of each of the following masses, including the phases those stars would go through and the approximate number of years it would spend in each phase

Star Mass	Phases it Would go Through	Approximate Number of Years in Each Phase
.75 x the sun		
3x the sun		
15 x the sun		

Step 3 - Reading Beyond the Lines

1. Compare the digital Star in a Box simulation model to the *Life Cycles of Stars Model.* How are these two models similar? How are they different?

2. When do you think it would be more useful to use a digital model like the Star in a Box simulation, and when would it be better to use an image like the *Life Cycles of Stars Model?* Support your answer with specific examples of what each model is helpful for.

How Do We Use Observable Properties to Identify Stars with Long and Stable Lifespans?

Objective: You just learned that there is a relationship between the mass of stars, their life span, and how characteristics such as luminosity and temperature change over their life spans. Through this activity, you will study a cluster of stars in order to identify what observable properties allow us to determine a star's mass, so that you can make predictions about their life spans and how they change over time.

Background: As you noticed in the image of the star cluster, stars exhibit many properties, so organizing our star data into a visual representation will make it easier for us to analyze the stars and look for connections between their observable properties, mass, and life span.You will be given a labeled chart and a series of stars to plot based on the data provided for each. From this star chart, you can deduce a lot of information about stars!

Each of the star data points has the following information:

- Star Name: the common or catalog name of the star
- Temperature: the temperature of the surface of the star (how fast molecules are moving on average)
- Luminosity: the rate at which a star emits energy compared to our sun (a fraction means it is dimmer than our Sun)
- Expected Life Span: the number of years the star is expected to exist before it runs out of fuel

Variables:

1. What variable is located on the x-axis of the chart?

 ____

 a. What unit is used to measure this variable?

 ____

 b. What is the range for this variable?

 ____

 c. What is unique about the x-axis on this chart?

 ____

2. What variable is located on the y-axis of the chart?

 ____

 a. What unit is used to measure this variable?

 ____

 b. What is the range for this variable?

 ____

Plotting Stars:

1. Hand out the "stars" to each member of your group. Have each person put 4-5 stars on the chart. Write down 3 observations about what you see so far.

Initial Observations of the Data

2. Work together to put the rest of the stars on the chart, then look for patterns in the star data. List patterns in the data in the left column, and state the evidence that you used to identify each pattern in the right column.

List the patterns in the star data below	State the evidence for each pattern in the star data below

3. Draw vertical lines on your chart to separate the stars by color. Then, below the x-axis of your chart, write the colors that correspond to each section.

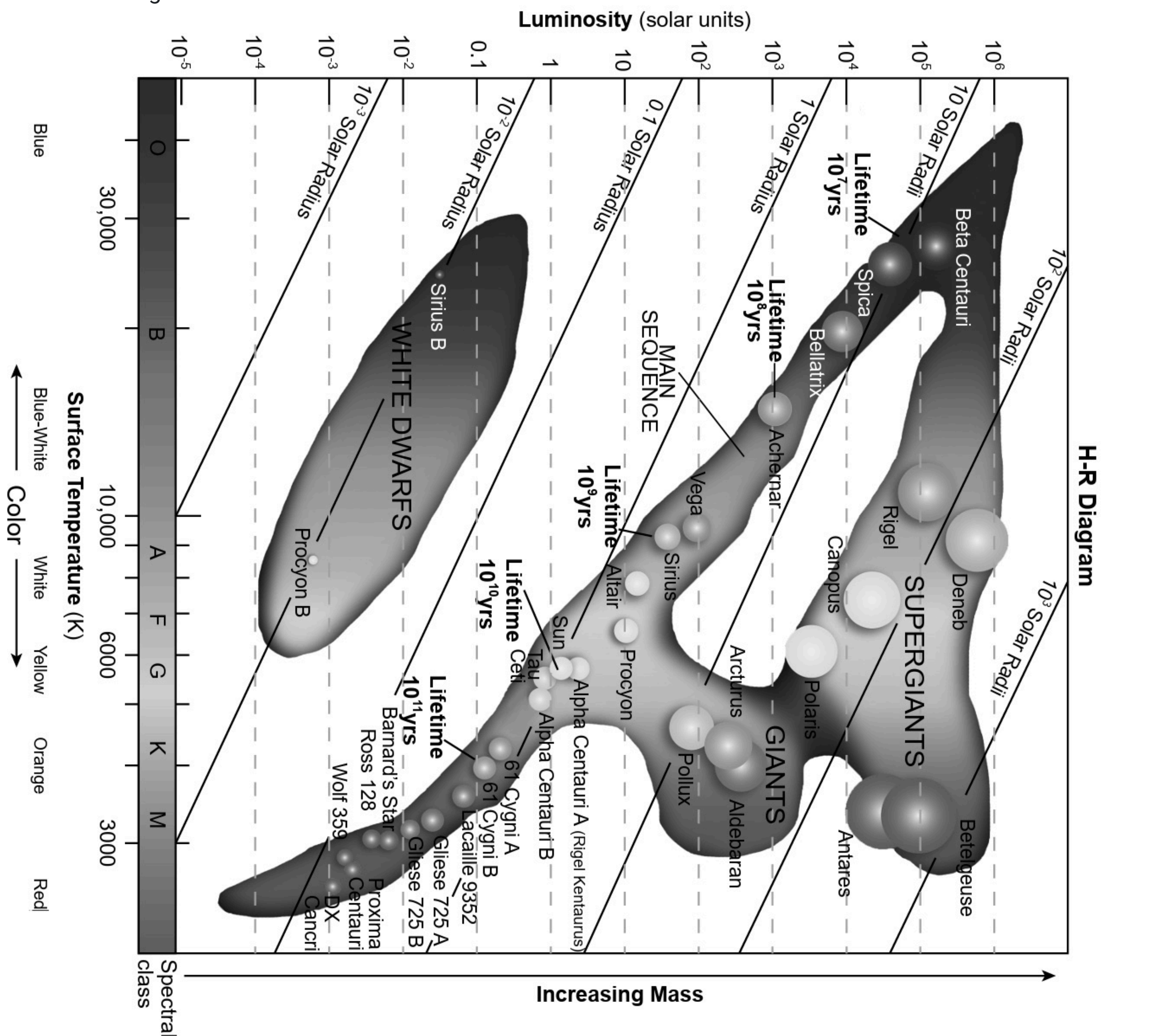
See-Think-Wonder

See What pattern did you observe in the data?	**Think** What do you think this pattern means?	**Wonder** What questions do you have about the pattern?

H-R Diagram Optional Extension

The H-R diagram you constructed mirrors H-R diagrams used by scientists, though different versions of the diagram contain slightly different information and may be written in slightly different ways. Scientists become fluent with reading different versions of this diagram by comparing it to ones they have seen before and interpreting any additional information given.

Compare your diagram with the one below and analyze this new diagram by answering the questions that follow the image.



Step 1 - Reading the Lines

1. Locate the sun and circle it clearly.

2. According to the diagram, how long is the lifetime of the sun?

3. Read the left side Y axis. What is it showing?

4. The numbers are written in scientific notation (using exponents).

When it says 10^6, it means 1 with 6 zeros after it (in standard notation, that is 1,000,000).
When it says 10^{-5}, it means to move the decimal point 5 to the left of the 1 (.00001). Rewrite the numbers in standard notation so they are easier to read.

5. View the X axis. What is it showing?

6. Mark where color is indicated on the graph.

7. Look at the right side Y axis. What is it showing?

8. What information is present on this diagram that was not on your H-R diagram?

Step 2 - Reading Between the Lines

1. Find a star with a lifespan of approximately 10,000,000 years.

   a. State the name of the star:

   b. What is the approximate temperature of that star?

c. What is the approximate luminosity of that star, in both scientific and standard notation?

d. What is the approximate size of that star (how many solar radii)?

e. What color is the star?

2. Find a white dwarf star.

a. State the name of the star:

b. What is the approximate temperature of that star?

c. What is the approximate luminosity of that star, in both scientific and standard notation?

d. What is the approximate size of that star (how many solar radii)?

e. What color is the star?

3. Find a supergiant star.

a. State the name of the star:

b. What is the approximate temperature of that star?

c. What is the approximate luminosity of that star, in both scientific and standard notation?

d. What is the approximate size of that star (how many solar radii)?

e. What color is the star?

Step 3 - Reading Beyond the Lines

1. Based on your experience creating and reading H-R diagrams, explain what this diagram shows you and when you might use it

2. When might the version of the H-R diagram that you made be more useful than this one? When might this one be more useful than the one you made? Support your answer with specific examples of how each one can be used.

3. Identify one star that is likely to be Earth-like, and potentially host life. Support your answer using specific information from the diagram.

4. Identify one star that is NOT likely to be Earth-like, and is not likely to host life. Support your answer using specific information from the diagram.

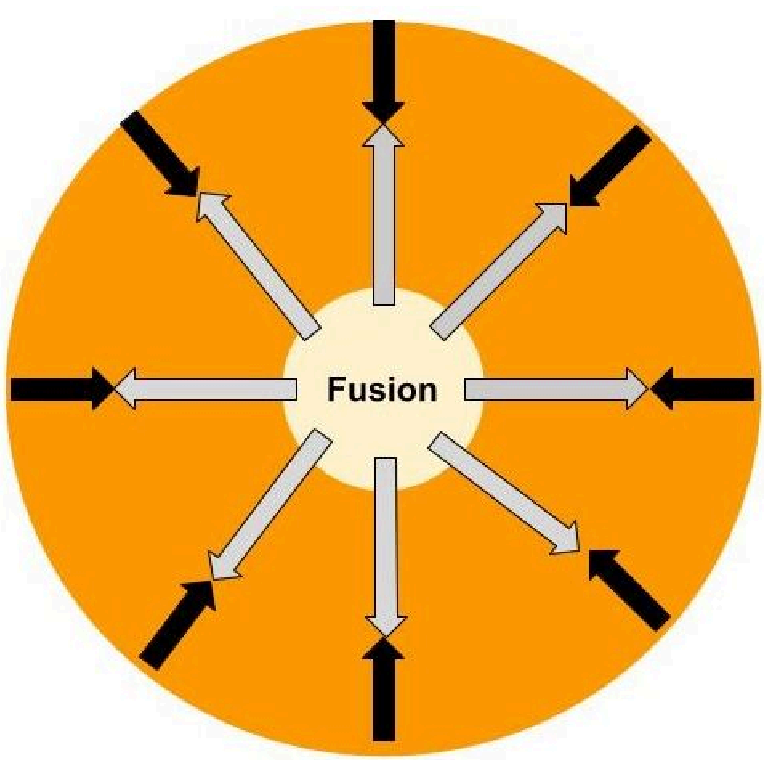
5. Identify one star that is likely to explode as a supernova. Support your answer using specific information from the diagram.

How and Why do Stars Change

Forces Within a Star
There are several forces acting on a star. Every object in the universe that has mass (e.g., atoms, planets, the Sun, yourself), generates gravity, a force that attracts other objects and particles towards its center. This force is very weak, but **the more mass an object has, the more gravity it generates**. Inside a star, gravity pulls inward, trying to collapse the star in on itself. You can picture this by imagining your hands squeezing a stress-ball. When gravity pulls hydrogen gas particles together inside a star, they collide more frequently and with more force, which leads to nuclear fusion. A small percentage of the mass from the hydrogen gas is lost when it is fused into helium, because it is converted into tremendous amounts of energy. This net gain in energy from nuclear fusion in the core pushes outward, trying to blast matter into space. Stars whose size changes relatively little have achieved a state of equilibrium, which means that the forces pushing in and the forces pushing out are equal and balance each other out. As long as the star has enough hydrogen fuel in its core to continue fusion reactions, the star will maintain equilibrium and stay as a main sequence star. This means that **when the star shrinks or expands, it is because the force of gravity that pushes inward and the internal fusion force that pushes outward are not equal anymore**. In other words, the forces are not in equilibrium.

1. Use the text above to label the parts of the diagram called **Forces Acting on a Star.**

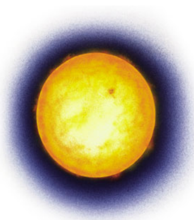
Forces Acting on a Star



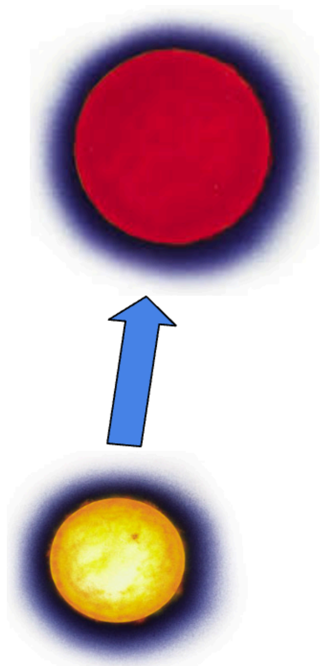
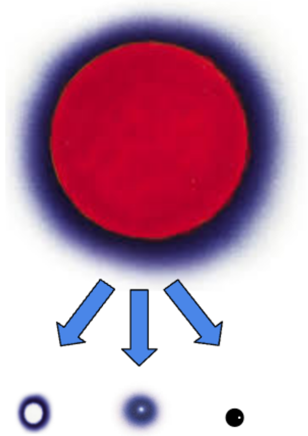
2. Make a prediction about the star in this diagram. Is it at equilibrium? How do you know?

Forces acting on a star lead to changes over their life cycles. Draw the forces pushing outward and inward at each stage of a star's life cycle. For each stage, decide on the size of gravity and fusion pressure arrows you want to draw so that they reflect the pattern in size change you observed during each stage.

Hydrogen gas and a dust cloud form new stars.	**Explanation** Be sure to discuss the role of the force of gravity and/or fusion force in your explanation for why new stars form from a hydrogen and dust cloud. Don't forget to include evidence to support your claim.
	

Stars change very little while they are in the Main Sequence stage.	**Explanation** Be sure to discuss the role of the force of gravity and/or fusion force in your explanation for why stars change very little while they are in the main sequence stage. Don't forget to include the evidence to support your claim.
	

Main Sequence stars change quickly when they grow into a Red Giant	**Explanation** Be sure to discuss the role of the force of gravity and/or fusion force in your explanation for why a Main Sequence star eventually grows in size to become a Red Giant. Don't forget to include evidence to support your claim.

	
Depending on a star's initial mass, the last stage of a star's life cycle is either a White Dwarf, Neutron Star, or Black Hole. These are some of the most dense objects in the universe.	**Explanation** Be sure to discuss the role of the force of gravity and/or fusion force in your explanation for why stars become much smaller and incredibly dense (compact) at the end of their life cycles.
	

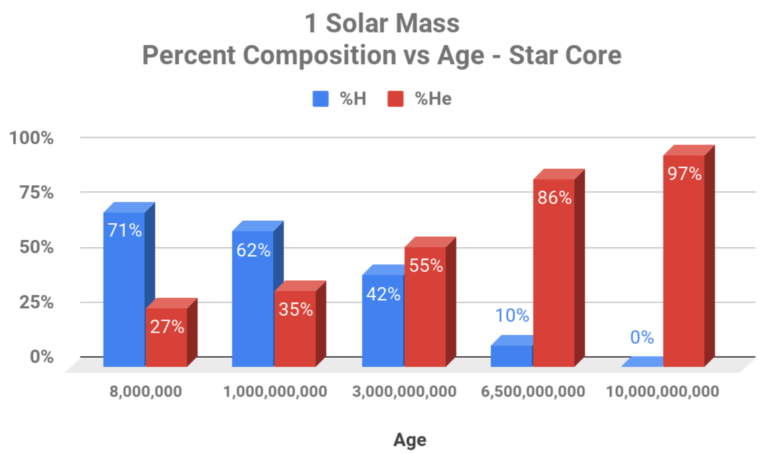
What connections are there between star life cycles and the rate of nuclear fusion in stars?
In order to start explaining the relationship between a star's initial mass and the length of a star's life cycle, think back to what you observed in Star in the Box and respond to the questions below. You will need to provide evidence for each response, so refer back to your observations from Star in the Box if necessary.

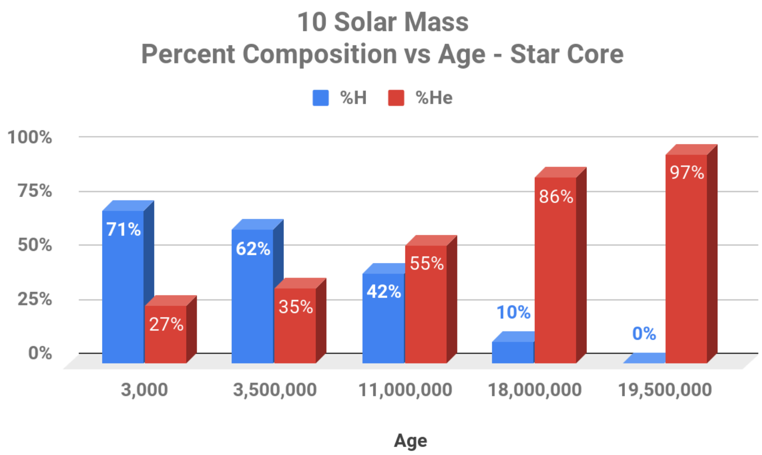
1. In which stage are stars the most stable? What explains this stability?

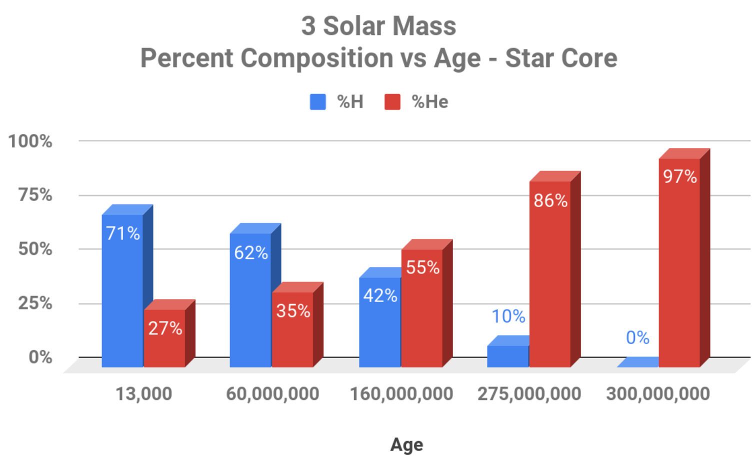
2. In what stage do stars spend most of their life cycles? Why?

3. Which stars spend the least time in this stage? High or low mass?

4. The Percent Composition vs. Age graphs (on the next page) show the hydrogen and helium ratios in main sequence stars of different initial masses. What connections do you see between the amount of time stars of different masses spend in the main sequence and the data below?




10 Solar Mass
Percent Composition vs Age - Star Core
%H
%He
100%
75%
50%
25%
0%
71%
27%
62%
35%
42%
55%
10%
86%
0%
97%
3,000
3,500,000
11,000,000
18,000,000
19,500,000
Age


3 Solar Mass
Percent Composition vs Age - Star Core
%H
%He
100%
75%
50%
25%
0%
71%
27%
62%
35%
42%
55%
10%
86%
0%
97%
13,000
60,000,000
160,000,000
275,000,000
300,000,000
Age

Summary Task

We recently completed a class consensus discussion. How did it go?

1. One thing that went well in the discussion:

2. One thing we can improve the next time we have a discussion:

3. One person who helped me learn today:

What did you learn from this person?

4. One idea that I contributed to my group or my class:

Explain what you know about the following questions, based on what we discussed today:

1. Why was studying our Sun alone not enough to identify *patterns* that we can use to make claims about which stars are most stable and which stars change the fastest?

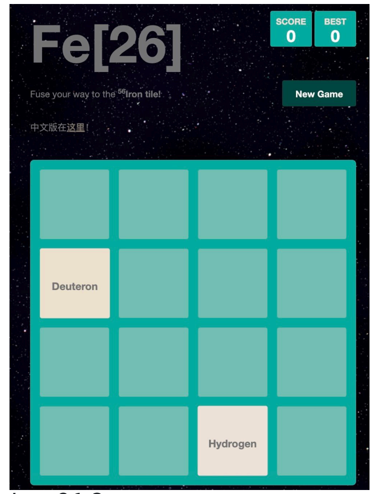
2. How was studying many stars helpful in identifying *patterns* that we can use to make claims about which stars are most stable and which stars change the fastest?

3. Why was it important to figure out why some stars are more stable than others?

4. Why might figuring out why things change and why they stay the same be something important to think about when investigating phenomena or finding solutions to problems?

Why do more massive stars change and die faster?

As you remember from the text, *Forces Within a Star*, inside a star gravity pushes hydrogen elements together so close and with such a force that sometimes these elements fuse into heavier elements. This game simulates just that! The goal is to make one tile of ^{56}Fe, or iron-56. A star needs to have a lot of gravity in order to push elements together tightly enough to create heavier elements. As you might remember, the more mass a star has, the more gravity it has.



Iron 26 Game

In order to play this game, you just need to press any of the four arrow keys to make a move. This causes all the tiles to slide as far to that side as possible. Every time you manage to combine two element tiles, the score will increase. Remember from the video that when two atoms are combined, some mass is transformed into energy. In the game, when you combine two elements, your score will increase, so for now let's call the points in the game **energy points**. The higher your score, the more mass was transformed into energy. Finally, when you reach Game Over, this means your star has died.

1. Review your notes about fusion first. Play the Iron [26] Game for 5 minutes, and try to relate what you are observing to what you know about fusion below.

2. Now consider the role of gravity. As you know by now, gravity pulls elements closer to each other. Remember too that the more gravity, the faster elements can fuse with each other. As an example, consider a star with low mass (like the Sun), and a star 20 times the mass of the Sun.

Revisit the Iron [26] game again, how do you think you can represent the difference in gravity of a low mass star and a high mass star in the game? Consider the following:

a. What role does gravity play in nuclear fusion?

b. How would this be different in a low mass star vs a high mass star? Why?

c. How would you show this using the nuclear fusion game?

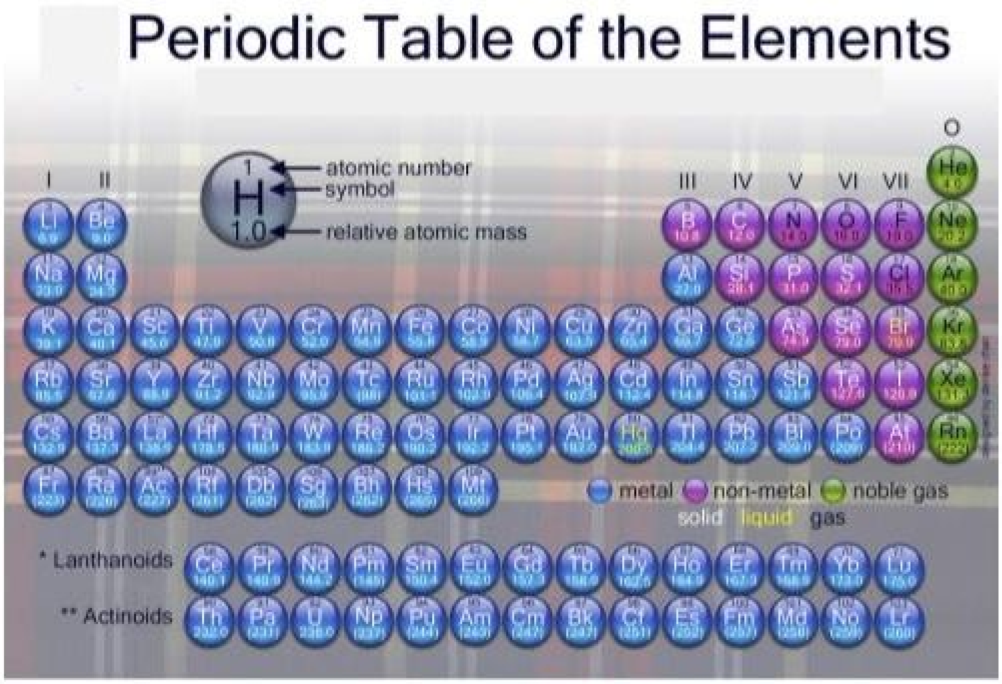
Using the Fe [26] game to model nuclear fusion in a star
Work with a partner in order to model nuclear fusion in a low and a high mass star with the *Fe [26] game*. One partner should act as timekeeper and recorder of observations, while the other partner plays the game.

1. The timekeeper/observer sets the timer to 90 seconds.
2. When the timekeeper starts the timer, the game player should use the method you agreed upon with your classmates to represent gravity in low mass stars.
3. Switch roles, this time to simulate gravity pushing light elements together in a high mass star. **Be sure that the timekeeper/observer records all observations of what is happening in the game.**

Our Sun and Stars with Comparable Mass	High Mass Stars
Gravity: Describe how you simulated gravity for these stars.	**Gravity: Describe how you simulated gravity for these stars.**
Observations (e.g. energy points, the elements that are formed):	**Observations (e.g. energy points, the elements that are formed):**

Part 1: What's the relationship between mass of a star and the elements it produces?
Since our Sun was formed, it has been fusing hydrogen to produce helium and energy. This is the process that occurs during the main sequence stage, which is most of a star's lifetime. When hydrogen in a star's core is all used up, the star begins to burn helium and forms progressively heavier elements like carbon, oxygen and so on, until iron is formed. All these processes release a lot of energy! But do all stars produce elements as heavy as iron?

1. Revisit your observations. How did the types of elements produced by your model of a low-mass star compare to the types of elements produced by your model of a high-mass star? Model both again if necessary. You can use the periodic table of elements below to explore details of the elements produced.



Periodic Table of Elements

2. What is the relationship between the mass of a star and the mass of the elements it produces?

3. What is the relationship between the mass of a star and the amount of energy it releases?

When chemical and physical processes occur, the amount and types of atoms involved are conserved -- in other words, the mass is conserved! But what about in nuclear reactions? The table below contains data associated with a few examples of nuclear fusion reactions that can take place in a star's core. Examine the *Example Nuclear Fusion Reactions* data below, then respond to the questions that follow.

Example Nuclear Fusion Reactions

Nuclear Fusion Reaction	Atoms Before Fusion	Protons + Neutrons Before Fusion	Atoms After Fusion	Protons + Neutrons After Fusion
Fusion of hydrogen	hydrogen-1 + hydrogen-2	3	helium-3	3
Fusion of helium	helium-3 + helium-4	7	beryllium-7	7
Fusion of beryllium and helium	beryllium-8 + helium-4	12	carbon-12	12
Fusion of carbon and helium	carbon-12 + helium-4	16	oxygen-16	16

1. Were the types of atoms conserved? Cite evidence from the table to support your response.

2. As you probably remember from middle school, the protons and neutrons of an atom make up all of its mass. Was mass (protons + neutrons) conserved in the nuclear fusion reactions? Cite evidence from the table to support your response.

Part 2: Why Do More Massive Stars Change and Die Faster?
Use evidence from the *Fe [26] game* to explain why a 20 solar mass star has a shorter life span than a 1 solar mass star?

1. As you know by now, the majority of a star's composition is hydrogen, so which has more hydrogen fuel to begin their life span, a 1 or 20 solar mass star?

2. Explain why a high-mass star has a much shorter lifespan than a low-mass star despite the fact that a high-mass star has much more hydrogen (fuel) to burn.

Part 3: Putting it All Together (Think-Talk-Open-Exchange)

Why are high-mass stars able to produce heavier elements than low-mass stars?	Why do high-mass stars have higher luminosities than low-mass stars?	Why is it that high-mass stars have much more initial hydrogen fuel to burn than low-mass stars, yet they have a much shorter lifespan?

Discussion Notes:

How are elements heavier than iron produced?

You may have noticed when using the Iron [26] computational model, that no elements heavier than iron were produced. So where does the energy required to produce elements like copper, gold, silver, and all other elements heavier than iron come from? The formation of elements heavier than iron requires much more energy than gravity can lead to in a star's core.

1. Consider what you have learned and observed as you have been investigating stars. Can you think of an event in a star that might provide the energy necessary for elements heavier than iron to be produced?

2. Supernova explosions produce elements like copper, gold, silver, and all other elements heavier than iron. What do you think explains why these elements were able to form in a supernova explosion? Use evidence from the Supernova 1054 video and text to support your response.

Star Life Cycles Model Rubric

Star Life Cycles	Proficient	Developing
Model	The model effectively and accurately shows what is happening within the Sun that explains why it has had stable properties long enough to sustain life and includes all of the components below: • Arrows that represent force of fusion pushing outward from the center of the Sun where nuclear fusion is taking place. • Arrows that represent the force of gravity pulling inward toward the center of the Sun. • The arrows represent fusion force and gravitational force as close to the same magnitude. The components of the model "speak for themselves" for the most part. **OR** There are legends, keys, or written captions to clarify the components.	The model is incomplete in showing what is happening within the Sun that explains why it has had stable properties long enough to sustain life, **missing one or more** of the components below: • Arrows that represent force of fusion pushing outward from the center of the Sun where nuclear fusion is taking place. • Arrows that represent the force of gravity pulling inward toward the center of the Sun. • The arrows represent fusion force and gravitational force as close to the same magnitude. The components of the model do not really "speak for themselves." **OR** Legends, keys, or written components are insufficient to clarify the model.
Stability and Change	Either the model or a written explanation cites the Sun's luminosity and temperature as evidence that it is a stable main sequence star with equal magnitudes of fusion force and gravitational force, and makes the connection to why the Sun's properties are currently changing very little. Either the model or a written explanation shows that the relatively low mass of the Sun is the reason why gravity leads to hydrogens fusing together at a slower rate than in heavier stars and the reason why the Sun has had stable properties (size, temperature ,and luminosity) for such a long time. Either the model or a written explanation shows that the Sun's relatively stable properties have allowed liquid water to exist on Earth long enough for life to evolve. Response to reflection prompt 1 clearly articulates why it is useful to understand stability and change when investigating other phenomena.	There is little or no consideration of the Sun's luminosity and temperature as evidence that it is a stable main sequence star with equal magnitude of fusion force and gravitational force and/or no connection is made to why the Sun's properties are currently changing very little. There is little or no consideration of the Sun's low mass as a reason why gravity leads to a slower rate of fusion than in heavier stars and is the reason why the Sun's properties (size, temperature ,and luminosity) have been stable for such a long time. There is little or no consideration of the Sun's relatively stable properties as a reason why liquid water has been able to exist on Earth long enough for life to evolve. Response to reflection prompt 1 does not clearly articulate why it is useful to understand stability and change when investigating other phenomena.

Patterns	Students explain why it was necessary to investigate stars at three different scales (solar system, supercluster, atomic) in order to explain star stability. Response to reflection 2 prompt clearly articulates why it is useful to look for patterns at different scales of a system when investigating phenomena.	There is little or no consideration of the necessity to investigate stars at three different scales (solar system, supercluster, atomic) in order to explain star stability. Response to reflection prompt 2 clearly articulates why it is useful to look for patterns at different scales of a system when investigating phenomena.
Student Self- Score	**Circle One** **Proficient** **Developing**	**Glow**: **Grow**:
Teacher Score	**Circle One** **Proficient** **Developing**	**Glow**: **Grow**:

Star Life Cycles Argument Rubric

Argument based on Star Life Cycles	Student makes a claim identifying which star is most likely to host an Earth-like planet. The claim is supported with relevant/accurate evidence from the star data set, investigations, or readings, including: • Temperature, luminosity, and placement HR-diagram Reasoning is provided to support the claim, including: • Connection between evidence cited and mass, stability, and life span. • Connection between stability and capacity to host and Earth-like planet	Student makes a claim identifying which star is most likely to host an Earth-like planet. The claim is weakly supported with evidence from the tar data set, investigations, or readings. Reasoning is not provided to support the claim.
Stability and Change	The argument cites the star's luminosity and temperature as evidence to support the claim and the reason it is predicted to be a stable main sequence star with equal magnitudes of fusion force and gravitational force, and makes the connection to why the stars's properties are currently changing very little. The argument cites the relatively low mass of the star as evidence to support the claim and the reason why it is predicted that gravity leads to hydrogens fusing together at a slower rate than in heavier stars, therefore likely to be a star that exhibits stable properties (size, temperature ,and luminosity) for a long time. The argument discusses why the stars' relatively stable properties means it's possible that liquid water has existed on a planet it hosts long enough for life to evolve. Response to reflection prompt 2 clearly articulates why understanding stability and change was useful in developing the argument.	There is little or no consideration of the star's luminosity and temperature as evidence to support the claim and the reason it is predicted to be a stable main sequence star with equal magnitudes of fusion force and gravitational force. There are no connections made to why the stars's properties are currently changing very little. There is little or no consideration of the star's mass as evidence for supporting the claim and the reason why it is predicted that gravity leads to hydrogens fusing together at a slower rate than in heavier stars. There is no connection made to why the star is likely to be a star that exhibits stable properties (size, temperature, and luminosity) for a long time. There is little or no consideration of why the stability of the star's properties means it's possible that liquid water has existed on a planet it hosts long enough for life to evolve. Response to reflection prompt 2 clearly articulates why understanding stability and change was useful in developing the argument.
Patterns	Patterns from different scales of the galaxy (solar system, supercluster, atomic) are cited in the argument. Response to reflection prompt 2 clearly articulates why investigating stars at three different scales of the galaxy (solar system, supercluster, atomic) was useful in developing the argument.	Patterns from different scales of the galaxy (solar system, supercluster, atomic) are not cited in the argument. Response to reflection prompt 2 clearly articulates why investigating stars at three different scales of the galaxy (solar system, supercluster, atomic) was useful in developing the argument.

Student Self- Score	**Circle One** **Proficient** **Developing**	**Glow**: **Grow**:
Teacher Score	**Circle One** **Proficient** **Developing**	**Glow**: **Grow**:

Relevance to your life: Think about everything that you have learned throughout this unit so far.

1. What is one idea and/or skill you learned that you think is important to teach someone in your family or community?

2. To whom do you intend to teach this idea and/or skill? Why do you think it is important for this person to learn this idea and/or skill?

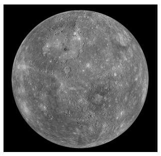
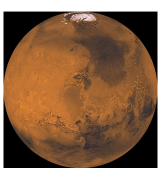
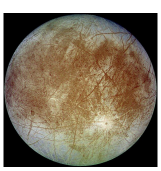
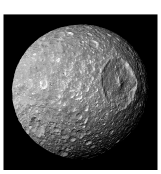
3. Is there something you learned in this unit you would like to research further? If so, would you be willing to present your findings to the class and/or school community?

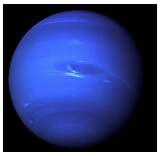
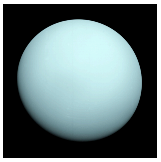
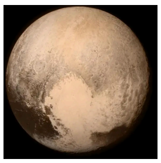
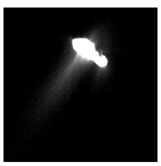
Planets and Orbits 5E

Unit 1 Discovering New Worlds	Earth and Space Science
Student Name:	

Which parts of the solar system have liquid water?

Water in Our Solar System

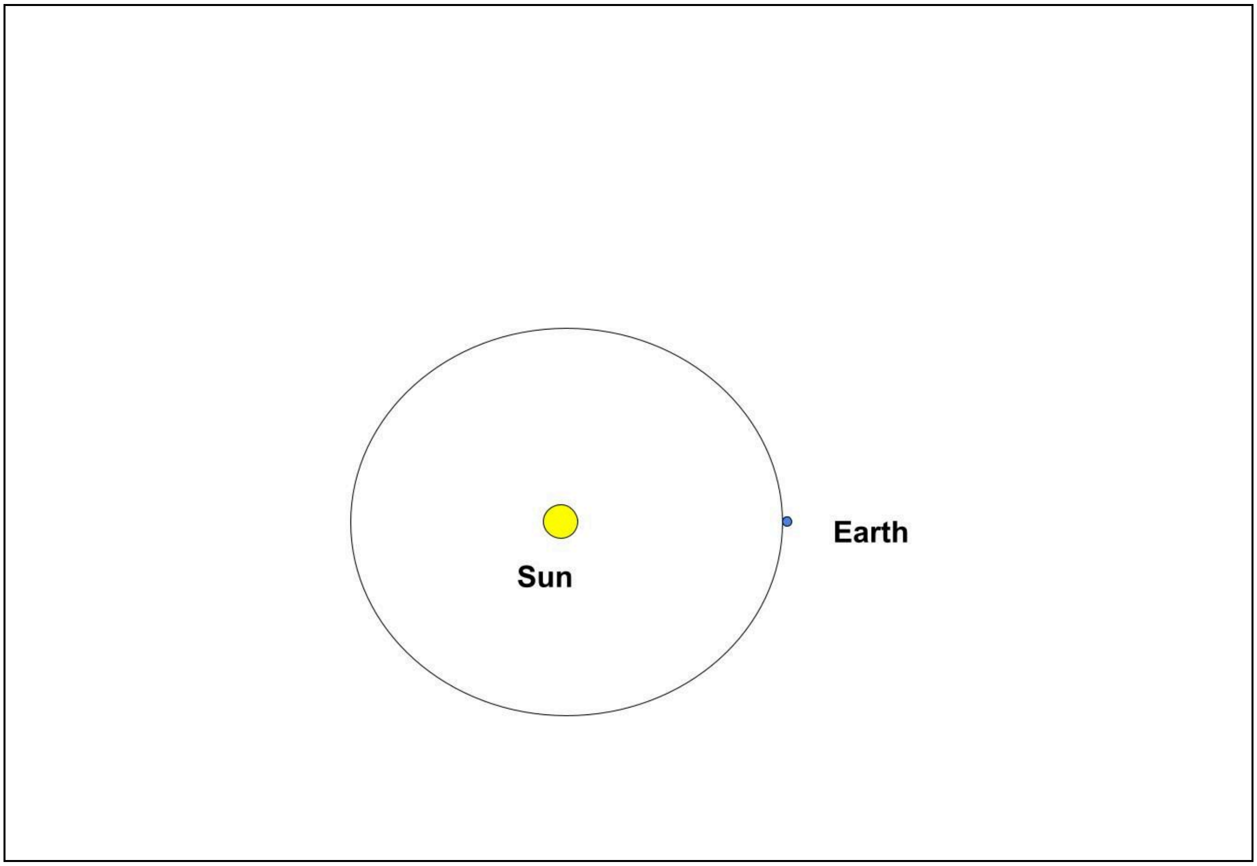
Celestial Object	Image	Existence of Water	Average Distance from the Sun (million km)
Mercury		• very small traces of water vapor in its atmosphere • atmosphere is much thinner than Venus' and contains much less water vapor.	57.9
Venus		• very small traces of water vapor in the atmosphere	108.2
Earth		• 71% of the Earth's surface is water • 96.5% of all the Earth's water is contained within the oceans as salt water • 3.5% is freshwater lakes and frozen water locked up in glaciers and the polar ice caps.	149.6
Mars		• almost exclusively ice • small amount present in the atmosphere as vapor • some transient liquid water on the Martian surface	227.9
Europa (Jupiter's moon)		• Water-ice crust at the surface • Might be an ocean below, with salty liquid water	778.4
Mimas (Saturn's moon)		• big ball of frozen water	1,426

Neptune		• large quantities of ice mixed in its atmosphere, which is mostly composed of hydrogen and helium • the percentage of water ice increases closer to the core	4,498
Uranus		• Possible water in the atmosphere and on the surface	2,871
Pluto		• Several small regions of ice	5,910
Comet Borrelly		• water is in solid ice form most of the time • every several years it shoots out a jet of vaporized water and dust	240

Describe the phenomenon
Talk with your group and tell the story of the phenomenon captured in the video and the *Water in the Solar System* table.

Develop an initial model
Use the diagram below to create an initial model explaining the phenomenon.

- Include data to support your model.
- Annotate your model, so it clearly explains the phenomenon.



What are orbits like in our solar system?

Examine and graph the *Solar System Orbital Data* below, **looking for evidence of patterns** that might help you form a claim about why water exists in different phases on different objects in the Solar System.

Solar System Orbital Data

Celestial Object	Average Distance from the Sun (AU)	Period of Revolution (Earth years)	Minimum Distance from Sun (AU)	Maximum Distance from Sun (AU)	Phase of majority of water
Mercury	.387	.241	0.307	0.467	vapor
Venus	.723	.615	0.718	0.728	vapor
Earth	1.00	1	0.983	1.017	liquid
Mars	1.523	1.88	1.381	1.666	ice
Comet Borrelly	3.590	6.80	1.350	5.830	Ice, but a great deal vaporizes every several years
Europa (Jupiter's moon)	5.203	11.87	4.950	5.459	Ice layer at surface, with liquid water ocean underneath
Mimas (Saturn's moon)	9.539	29.46	9.041	10.124	
Uranus	19.185	84.03	18.324	20.078	ice
Neptune	30.061	164.82	29.709	30.386	ice
Pluto	39.479	248.06	29.658	49.304	ice

Note: One AU is equivalent to Earth's average distance from the Sun.

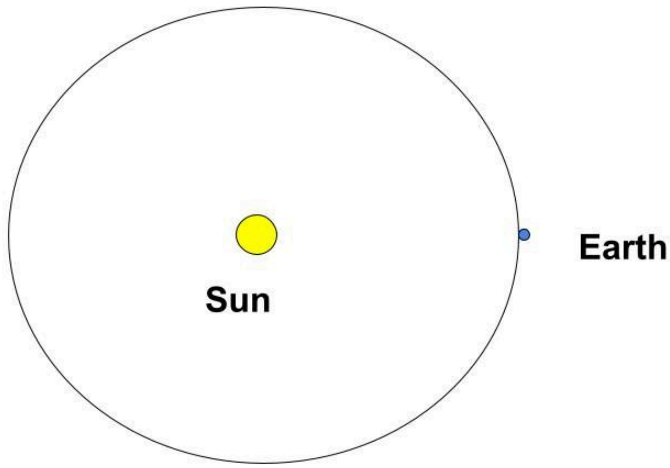
See-Think-Wonder

See	Think	Wonder
A pattern I noticed:		
A pattern I noticed:		
A pattern I noticed:		
A pattern someone in my group noticed:		
A pattern someone in another group noticed:		

Revising Solar System Models

Revisit your model from the Engage phase. Use the patterns you observed in the solar system orbital data to revise your model.

- Include data to support your model.
- Annotate your model, so it clearly explains the phenomenon.



Summary Task

We recently completed a class consensus discussion. How did it go?

1. One thing that went well in the discussion:

2. One thing we can improve the next time we have a discussion:

3. One person who helped me learn today:

What did you learn from this person?

4. One idea that I contributed to my group or my class:

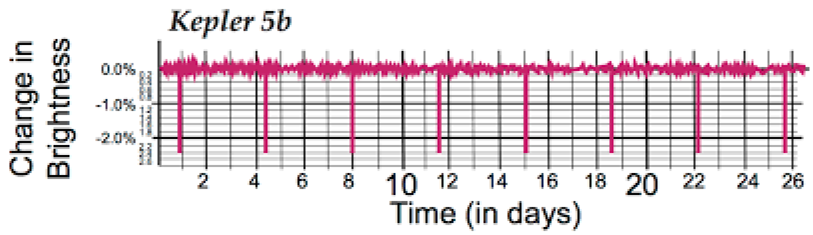
Explain what you know about the following questions, based on what we discussed today:

5. What were the patterns you used to develop an explanatory model for the different phases of water on different objects orbiting the Sun? How did you prove those patterns exist?

6. What did you do to make it easier to identify the patterns you used to develop an explanatory model for the different phases of water on different objects orbiting the Sun?

How far are the exoplanets in our data set from their stars?

We have been able to obtain transit data from the stars and exoplanets we are investigating. Analyze and interpret the transit data for each of the exoplanets in our data set in order to determine their orbital periods. From there we can try to identify relationships between orbital period and other orbital variables in our own solar system data that we can use to determine more about the orbits of exoplanets.



What patterns do we see in the relationship between orbital period and other orbital variables in our solar system?

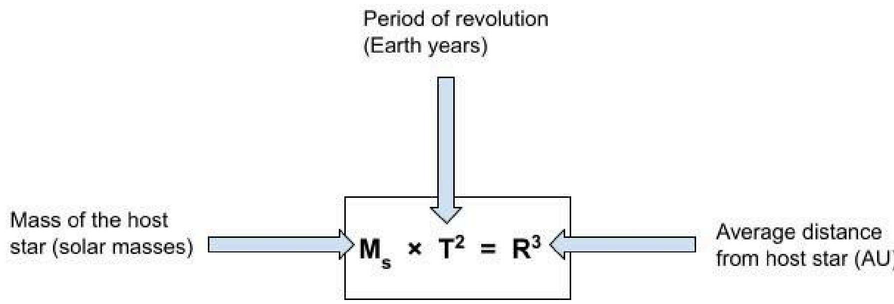
1. Review the *Solar System Orbital Data* table. Describe the relationships among orbital period and other orbital variables.

2. When scientists identify relationships between variables, sometimes it is useful to derive equations that describe these relationships. In fact, these equations can then be applied to different contexts.

Enter the data for the relationship you identified into an Excel spreadsheet and use Excel to help you derive an equation that describes that relationship. Write that equation below.

Kepler's Third Law

Kepler's Third Law of Planetary Motion

Mathematical Model	
Verbal Model	

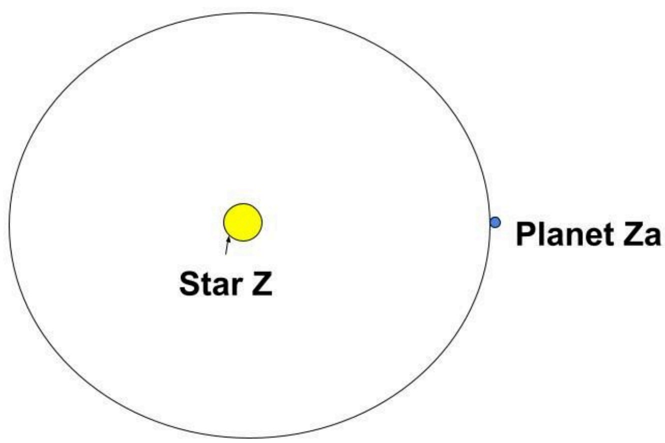
Applying our mathematical model of orbits to exoplanets

Part 1: Average distance vs orbital period: How can we apply our mathematical model?

1. Examine the orbital data below. Then complete the diagram by depicting where the orbits of Planet Zb, Planet Zc, and Planet Zd would lie with respect to Planet Za. Be sure to provide evidence and reasoning from the mathematical model above to support your claims.

Data on Objects Orbiting Star Z

Celestial Object	Period of Revolution (Earth years)
Planet Za	1.2
Planet Zb	3.5
Planet Zc	0.80
Planet Zd	1.8



2. Use the mathematical representation of the relationship between a planet's average distance from its host star and orbital period to calculate the data missing from the table.

Celestial Object	Mass of Host Star (solar masses)	Period of Revolution (Earth years)	Average Distance from Host Star (AU)
Planet Ya	.7	.58	
Planet Yb	6.5	1.45	

Part 2: What is the average distance between exoplanets in our data set and their host stars?

1. Use the mathematical model your class has derived to predict the average distance between each planet in our exoplanet data set and their host stars. You have already determined the orbital period for each exoplanet and the mass of their host stars have been provided by NASA.

Exoplanet Orbital Data

Exoplanet Name	**Mass of Host Star** (solar masses)	**Period of Revolution** (Earth years)	**Average Distance from Host Star** (AU)	**Habitable Zone Inner Limit** (AU)	**Habitable Zone Outer Limit** (AU)	**Is it possible that this planet stays within the habitable zone?**
Kepler-79 b	1.165	0.0369		1.711	4.229	
Kepler-18 b	0.972	0.00962		1.463	3.227	
Kepler-186 f	0.544	0.356		0.242	0.464	
Kepler-442 b	0.6100	0.3078		0.252	0.531	
TOI-2257 b	.33	0.0964		.079	.167	
HD-20782 b	0.96	1.605		2.613	4.632	
Trappist-1 f	0.089	0.0252		0.023	0.048	
Trappist-1 g	0.089	0.0340		0.023	0.048	

1. Based on your calculations, which exoplanets travel within the habitable zone when they are at the average distance from their star? Be sure to cite evidence.

2. Does this mean that they orbit within the habitable zone throughout their orbital period of revolution around their star? What other information would you like to have?

Summary Task

We recently completed a class consensus discussion. How did it go?

1. One thing that went well in the discussion:

2. One thing we can improve the next time we have a discussion:

3. One person who helped me learn today:

What did you learn from this person?

4. One idea that I contributed to my group or my class:

Explain what you know about the following questions, based on what we discussed today:

5. The graph of orbital period vs semi major axis length allowed us to identify a pattern in the relationship between these two variables. How did our mathematical model (Kepler's Third Law) help us describe this pattern more precisely?

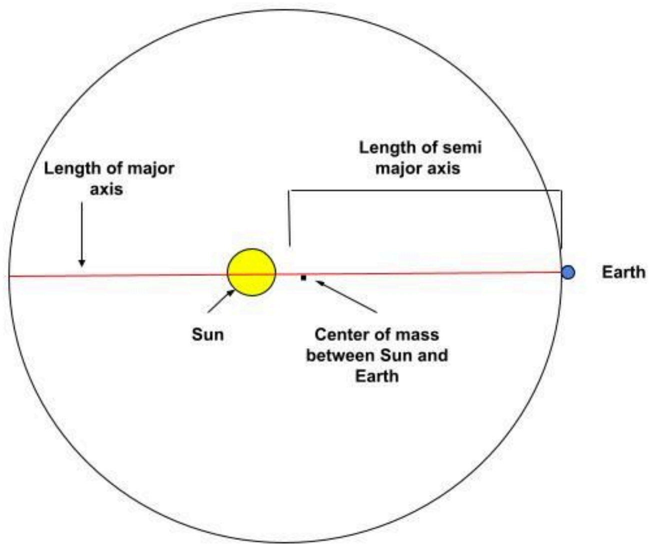
6. How were our mathematical models (Kepler's 1st and 3rd Law) useful for determining whether exoplanets orbit within the habitable zone of their host star?

How do we determine shapes of orbits?

Kepler's First Law of Planetary Motion
The shape of an orbit determines whether a planet stays within a habitable zone as it revolves around its host star. This has great implications for the existence of liquid water and the possibility of life.

There are a few important terms in this model.

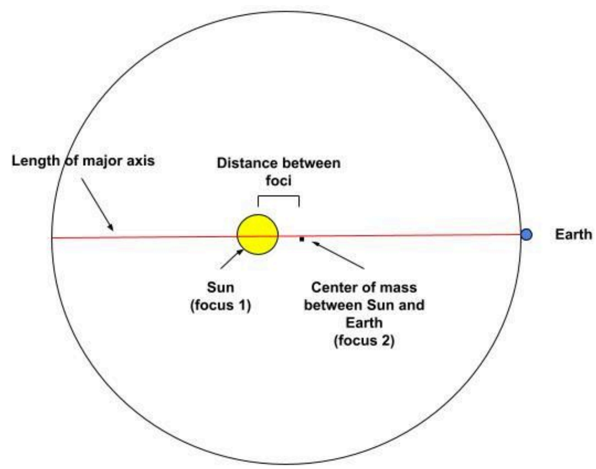
Length of Major Axis
The diagram below depicts the Earth-Sun system. While Earth's orbit is close to being circular, it is actually not a perfect circle. The length of the major axis is the distance between the two points in an orbit that are furthest away from each other. The semi major axis is half the major axis, and is equal to the average distance between the planet/object and its host star.



Which exoplanets orbit in the habitable zone?

Distance Between Foci

Is the Sun the center of our Solar System? This is close to being correct! While the planets in our solar system revolve around the Sun, the Sun actually revolves around the center of mass of our solar system, which is based on the relative position and the mass of all objects in the solar system. Since the Sun contains 99.9% of the mass of the solar system, the center of mass is located almost at the Sun, so it looks like the Sun is at the very center of our solar system. The solar system center of mass and the Sun are known as foci. Together, these are an important part of Kepler's mathematical model for orbital shapes.



The equation below is the mathematical model for orbital shape, or orbital eccentricity. Orbital eccentricity is a number that indicates how circular vs elliptical an orbit is. You will be given orbital eccentricity data for each exoplanet in our performance task data set and use the semi major axis lengths you have determined to calculate the distance between foci in each exoplanet's solar system. This will allow you to construct a model of each exoplanet-star system and predict whether the exoplanet will stay within the habitable zone throughout its orbital period.

Kepler's First Law of Planetary Motion

Mathematical Model	$\underbrace{e}_{\text{Orbital eccentricity}} = \dfrac{\overbrace{f}^{\text{distance between foci (AU)}}}{\underbrace{d}_{\text{length of major axis (AU)}}}$
Verbal Model	

Constructing an Orbit
Use Kepler's First Law of Planetary Motion to calculate the scaled distance between foci in the solar system of the exoplanet that was assigned to you. Then use the scaled distance between foci, scaled length of major axis, and materials provided by your teacher to construct that exoplanet's orbit in order to determine whether it stays within the habitable zone throughout an orbit around its host star.

Note: Habitable Zone should be measured from the focus that represents the star.

Orbital Data

Celestial Object	Scaled Length of Major Axis (cm)	Length of String) (cm)	Eccentricity of Orbit	Scaled Distance Between Foci (cm)	Scaled Habitable Zone Range (cm)	Does the planet stay within the habitable zone?
Earth	60	30.5	0.0167		28.5 - 34.5	
Kepler 186 f	50	26	0.040		14.8 - 28.3	
Kepler 442 b	50	26	0.040		16.3 - 34.4	
TOI-2257 b	25	18.7	0.496		6.8 - 14.4	
Trappist-1 f	5.7	2.9	0.010		1.7 - 3.6	
Trappist-1 g	7.0	3.5	0.002		1.7 - 3.6	

Planets and Orbits Model Rubric

Planets and Orbits	Proficient	Developing
Model based on Planets and Orbits	The model effectively and accurately shows the characteristics of Earth's orbit that explain why it maintains liquid water and includes all of the components below: • A representation of Earth orbiting within the habitable zone of our solar system throughout an entire orbit around the Sun • Kepler's 1st law and where the variables are represented in the model The components of the model "speak for themselves" for the most part. **OR** There are legends, keys, or written captions to clarify the components.	The model is incomplete in showing what is happening within the Sun that explains why it has had stable properties long enough to sustain life, **missing one or more** of the components below: • A representation of Earth orbiting within the habitable zone of our solar system throughout an entire orbit around the Sun • Kepler's 1st law and where the variables are represented in the model The components of the model do not really "speak for themselves." **OR** Legends, keys, or written components are insufficient to clarify the model.
Patterns	Written explanation includes patterns identified by graphing solar system data and from the algebraic equation, Kepler's 1st law, as evidence to support the model. Response to reflection prompt 1 clearly articulates why creating mathematical representations from data, like graphs and algebraic equations, can be useful in identifying patterns that can serve as evidence to develop a model for other phenomena.	There is little or no consideration of patterns identified by graphing solar system data and from the algebraic equation, Kepler's 1st law, as evidence to support the model. Response to reflection prompt 1 does not clearly articulate why creating mathematical representations from data, like graphs and algebraic equations, can be useful in identifying patterns that can serve as evidence to develop a model for other phenomena.
Scale, Proportion, and Quantity	Written explanation indicates how the algebraic equation, Kepler's First Law, was useful for making a claim about the eccentricity (shape) of Earth's orbit. Response to reflection prompt 1 clearly articulates how an algebraic equation can be useful in developing a model for other phenomena.	There is little or no consideration of how the mathematical equation, Kepler's 1st law, was useful for making a claim about the eccentricity (shape) of Earth's orbit. Response to reflection prompt 1 does not clearly articulate how an algebraic equation can be useful in developing a model for other phenomena.
Student Self- Score	**Circle One** **Proficient** **Developing**	**Glow**: **Grow**:

<table>
<tr><th>Teacher Score</th><th>Circle One

Proficient   Developing</th><th>Glow:

Grow:</th></tr>
<tr><td>Argument based on the unit</td><td>Student makes a claim identifying which star is most likely to host an Earth-like planet.

The claim is supported with relevant/accurate evidence from the star and exoplanet data set, investigations, or readings, including:
Temperature, luminosity, and placement HR-diagram
Length of planets' semi major axis (average distance), eccentricity (shape), and habitable zone range
Reasoning is provided to support the claim, including:
Connection between evidence cited and mass, stability, and life span of the stars.
Connection between stability of the stars and capacity to host an Earth-like planet.
Connection between evidence cited from planet orbital data and the potential existence of liquid water on the planet.
Connection between the potential existence of liquid water on the planet and its capacity to sustain life.</td><td>Student makes a claim identifying which star is most likely to host an Earth-like planet.

The claim is weakly supported with evidence from the tar data set, investigations, or readings.

Reasoning is not provided to support the claim.</td></tr>
<tr><td>Patterns</td><td>Argument includes the patterns identified from the mathematical equations, Kepler's 1st and 3rd law, as evidence for the claim.

Response to reflection prompt 1 clearly articulates why creating mathematical representations from data, like graphs and equations, can be useful in identifying patterns that can serve as evidence for a claim in an argument.</td><td>There is little or no consideration of patterns identified from the mathematical equations, Kepler's 1st and 3rd law, as evidence to the claim.

Response to reflection prompt 1 clearly articulates why creating mathematical representations from data, like graphs and equations, can be useful in identifying patterns that can serve as evidence for a claim in an argument.</td></tr>
<tr><td>Scale, Proportion, and Quantity</td><td>Argument includes the mathematical equations, Kepler's 1st and 3rd laws, as scientific reasoning for why the planet orbital data cited as evidence supports the claim.

Response to reflection prompt 1 clearly articulates how algebraic equations were useful in making claims for their argument.</td><td>There is little or no consideration of how mathematical equations, Kepler's 1st and 3rd laws, serve as scientific reasoning for why the planet orbital data cited as evidence supports the claim.

Response to reflection prompt 1 does not clearly articulate how algebraic equations were useful in making claims for their argument.</td></tr>
</table>

Student Self- Score	**Circle One** **Proficient** **Developing**	**Glow**: **Grow**:
Teacher Score	**Circle One** **Proficient** **Developing**	**Glow**: **Grow**:

Relevance to your life: Think about everything that you have learned throughout this unit so far.

1. What is one idea and/or skill you learned that you think is important to teach someone in your family or community?

2. To whom do you intend to teach this idea and/or skill? Why do you think it is important for this person to learn this idea and/or skill?

Unit Closing

Unit 1 Discovering New Worlds	Earth and Space Science
Student Name:	

Final Task Rubric

	Level 4: Advanced	Level 3: Proficient	Level 2: Developing	Level 1: Beginning	Level 0: Not Evident
Claim	Clearly stated claim that specifies either Kepler-442 b, Kepler-186 f, Trappist-1 f or Trappist-1 g as most likely to be a habitable planet. Evaluates other claims and justifies why own claim is the strongest with underlying scientific ideas.	Clearly stated claim that specifies either Kepler-442 b, Kepler-186 f, Trappist-1 f or Trappist-1 g as most likely to be a habitable planet.	Clearly stated claim that specifies any other planet in the data set as most likely to be a habitable planet.	Claim about which exoplanet from the data set is most likely to be habitable is not clearly stated.	No claim is made about which exoplanet from the data set is most likely to be habitable.
Evidence	Evidence includes: • position of the planet's star on the HR diagram • patterns of star stability and lifespan observed in Star in the Box • distance at which the planet orbits around its star • whether the planet orbits within the habitable zone throughout a revolution • density and/or diameter of the planet • mass of the planet as evidence of an atmosphere	Evidence includes: • position of the planet's star on the HR diagram • patterns of star stability and lifespan observed in Star in the Box • distance at which the planet orbits around its star • whether the planet orbits within the habitable zone throughout a revolution • density and/or diameter of the planet	1-2 of the following pieces of evidence are missing: • position of the planet's star on the HR diagram • patterns of star stability and lifespan observed in Star in the Box • distance at which the planet orbits around its star • whether the planet orbits within the habitable zone throughout a revolution • density and/or diameter of the planet	3 or more of the following pieces of evidence are missing: • position of the planet's star on the HR diagram • patterns of star stability and lifespan observed in Star in the Box • distance at which the planet orbits around its star • whether the planet orbits within the habitable zone throughout a revolution • density and/or diameter of the planet	No relevant evidence is provided.

Link Between Evidence and Claim	Links between evidence and claim include: • Connections between the position of the planet's star on the HR diagram, the star's mass, and the star's lifespan and stability are made explicit and linked to habitability, using evidence of relevant patterns in our solar system. • A connection between the distance at which a planet orbits from its star and temperature is made explicit and linked to habitability, using underlying scientific ideas. • A connection between whether the planet orbits within the habitable zone throughout a revolution the potential existence of liquid water is made explicit and linked to habitability, using underlying scientific ideas. • A connection between density and/or diameter of the planet and the planet's composition is made explicit and linked to habitability, using evidence of relevant patterns in our solar system. • A connection between the mass of the planet and the potential for and atmosphere is made explicit and linked to habitability, using evidence of relevant patterns in our solar system.	Links between evidence and claim include: • Connections between the position of the planet's star on the HR diagram, the star's mass, and the star's lifespan and stability are made explicit and linked to habitability, using evidence of relevant patterns in our solar system. • A connection between the distance at which a planet orbits from its star and temperature is made explicit and linked to habitability, using underlying scientific ideas. • A connection between whether the planet orbits within the habitable zone throughout a revolution the potential existence of liquid water is made explicit and linked to habitability, using underlying scientific ideas. • A connection between density and/or diameter of the planet and the planet's composition is made explicit and linked to habitability, using evidence of relevant patterns in our solar system.	1-2 of the following links between evidence and claim are missing: • Connections between the position of the planet's star on the HR diagram, the star's mass, and the star's lifespan and stability are made explicit and linked to habitability,using evidence of relevant patterns in our solar system. • A connection between the distance at which a planet orbits from its star and temperature is made explicit and linked to habitability, using underlying scientific ideas. • A connection between whether the planet orbits within the habitable zone throughout a revolution the potential existence of liquid water is made explicit and linked to habitability, using underlying scientific ideas. • A connection between density and/or diameter of the planet and the planet's composition is made explicit and linked to habitability, using evidence of relevant patterns in our solar system.	3 or more of the following links between evidence and claim are missing: • Connections between the position of the planet's star on the HR diagram, the star's mass, and the star's lifespan and stability are made explicit and linked to habitability, using evidence of relevant patterns in our solar system. • A connection between the distance at which a planet orbits from its star and temperature is made explicit and linked to habitability, using underlying scientific ideas. • A connection between whether the planet orbits within the habitable zone throughout a revolution the potential existence of liquid water is made explicit and linked to habitability, using underlying scientific ideas. • A connection between density and/or diameter of the planet and the planet's composition is made explicit and linked to habitability, using evidence of relevant patterns in our solar system.	No links between evidence and claim are provided.

Note about SEP#6 - Arguing from Evidence in this unit: The argument students are asked to develop in this unit is at the NGSS middle school level. We encourage teachers to use the performance task argument in this unit as a formative assessment of whether students are proficient in argument at the middle school level. This will provide data that can be used to inform support for arguing from evidence at the NGSS high school level during subsequent units in this course.