PHYSICS

Stars & the Big Bang

Why do stars shine and will they shine forever?

OpenSciEd

HIGH SCHOOL SCIENCE

TEACHER EDITION

Why do stars shine and will they shine forever?

Stars & the Big Bang: Stars

OpenSciEd Unit P.6

OpenSciEd

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UNIT OVERVIEW

Why do stars shine and will they shine forever?

This unit is anchored by historical accounts of stars that suddenly appear and then disappear a short time later. Students wonder about how some stars appear unchanging, while these stars change so drastically within such a short period of time. That gets students wondering about why stars shine, and what could cause stars to change. They organize their questions in terms of matter, energy, and forces, and decide to look more closely at the places in the sky where these historical events took place using modern technology. In **Lesson Set 1** (Lessons 2-5), students investigate photos and spectra of the remnants of these events, and then develop two sets of research questions to investigate in small groups, before coming together to come to consensus in Lesson 5 around the fusion and the lifecycle of stars. Students' small-group internet research is scaffolded by a set of tools that are introduced strategically across the unit: the *Planning for Obtaining Information Tool,* the *Obtaining Information Tool, and* the *Evaluating Sources of Information Tool.*
Students figure out that over millions or even billions of years, stars convert lighter elements like hydrogen and helium into heavier and heavier elements, and this motivates the next Lesson Set, as students wonder where these lighter elements came from and how these matter changes could affect the matter in the universe over time. In **Lesson Set 2** (Lessons 6-7), students follow clues from spectra of the Universe to engage in a third internet research cycle using the research tools from Lesson Set 1 and the *Planning for Communicating Information Tool*. Then they come to consensus around evidence for a hot dense Universe 14 billion years ago that has expanded into what we see today, a theory known as the Big Bang. They read about what it means for the Big Bang to be a theory, and reflect on the nature of science.
Lesson 7 is intended to be the last lesson of the unit, and the OpenSciEd High School Physics course, and thus the last lesson of the OpenSciEd K-12 program. The lesson is designed to help students think metacognitively about the practices they have developed over the OpenSciEd High School program for asking and answering science questions, and the cross-cutting conceptual frames they can apply to help them make sense of what they figure out. They develop driving questions that they will not be able to answer in class, but that students are encouraged to pursue answers to through independent online research, future science classes, a career in STEM, and/or a lifetime of curiosity.

Building Toward NGSS Performance Expectations

HS-ESS1-1:
Develop a model based on evidence to illustrate the life span of the sun and the role of nuclear fusion in the sun's core to release energy that eventually reaches Earth in the form of radiation.

HS-ESS1-2:
Construct an explanation of the Big Bang theory based on astronomical evidence of light spectra, motion of distant galaxies, and composition of matter in the universe.

HS-ESS1-3:
Communicate scientific ideas about the way stars, over their life cycle, produce elements.

HS-PS1-8:
Develop models to illustrate the changes in the composition of the nucleus of the atom and the energy released during the processes of fission, fusion, and radioactive decay.

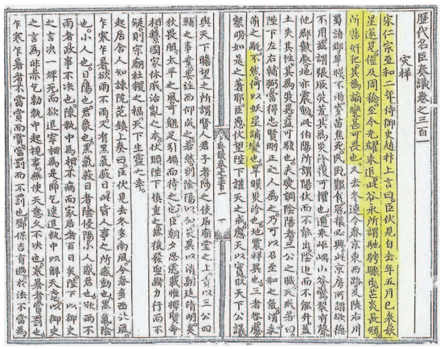
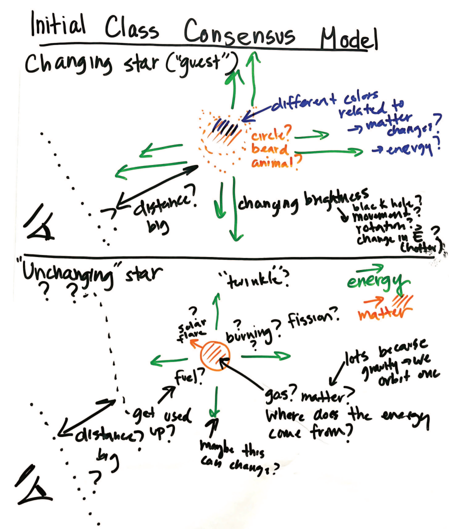
UNIT STORYLINE

Unit Question: Why do stars shine and will they shine forever?

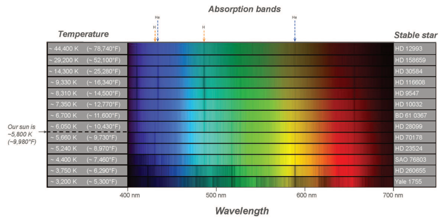
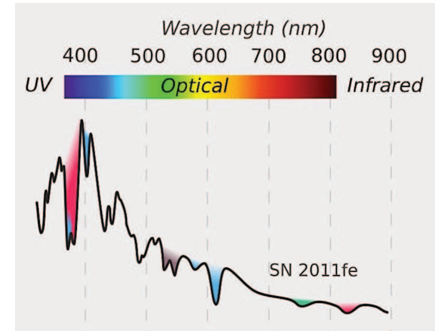
How students will engage with each of the phenomena

HANDS-ON/ LAB ACTIVITIES | VIDEOS OR IMAGES | DATA SETS | READINGS | COMPUTER INTERACTIVES

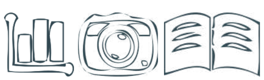
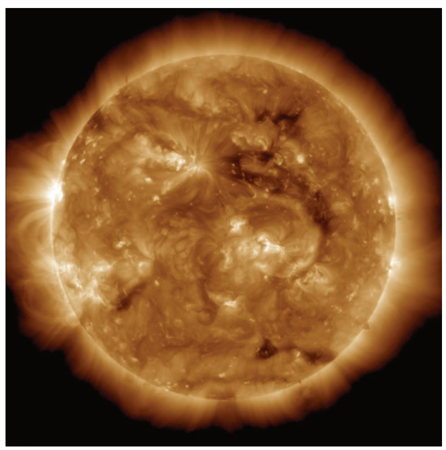
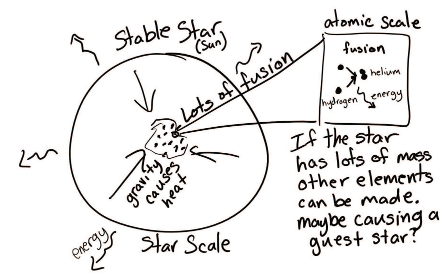
Lesson Set 1: How are stars born, and how do they die?

Lesson Question	Phenomena or Design Problem	What we do and figure out	How we represent it
LESSON 1 Lesson Set 1 2 days **Why do some stars seem unchanging, while others appear briefly, change dramatically, and fade away?** Anchoring Phenomenon	 *Several times in history, a star has appeared in the sky suddenly and disappeared after a short time. These events were recorded in writings, petroglyphs, and more recently in photographs.*	We examine historical evidence that some stars appear in the night sky even though we could not see a star there previously. The star fades away and seems to disappear. We map these events on a star map and look for patterns. We figure out: • A guest star is a star that appears and then seems to disappear a short time later. • Guest stars are distributed across the sky but seem to be concentrated along the plane of our galaxy (the Milky Way).	

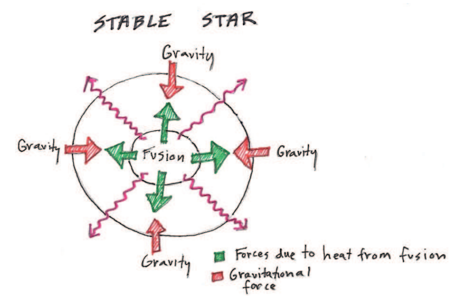
⇓ **Navigation to Next Lesson:** What do we see when we point a telescope at these locations that we have mapped?

Lesson Question	Phenomena or Design Problem	What we do and figure out	How we represent it
LESSON 2 Lesson Set 1 1 day **How does the matter in guest stars compare to stable stars?** Investigation 	 *Semi-spherical shaped clouds of dust and gas can be seen in telescopic images from locations in the sky where guest stars were once observed.*	We compare photos of the parts of the sky where some of these guest star events were observed and notice remnants of what looks like gas or dust. We analyze spectra to determine the composition of the matter that these remnants are made of and its temperature. We compare the spectra of stable stars to the spectra of remnants and add to our Progress Trackers. We ask new questions and add them to our Driving Question Board. We figure out: • Stable stars are made of mostly *hydrogen* and *helium*. • *Hydrogen* and *helium* are the two lowest-mass elements. • Temperatures of stable stars range from thousands to ten thousands °C or °F. Temperatures of guest star remnants are millions °C or °F. • Guest star remnants contain elements other than *hydrogen* and *helium* and in some cases no *hydrogen* and *helium.*	 *Adapted from: Dr. Heloise F. Stefanie*

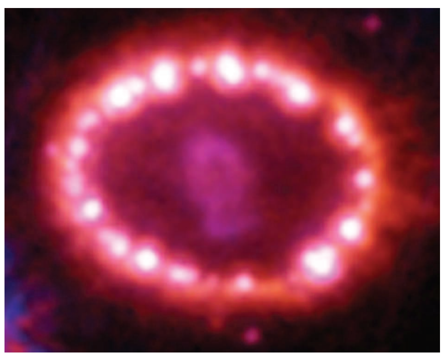
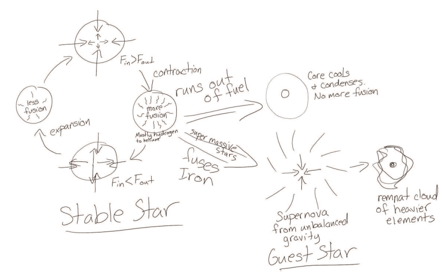
⇓ **Navigation to Next Lesson:** We have new questions about if/how stars and guest stars change, and what keeps most stars stable, that are related to matter, energy perspectives.

Lesson Question	Phenomena or Design Problem	What we do and figure out	How we represent it
LESSON 3 Lesson Set 1 2 days **What is happening with matter and energy in stable stars, like our Sun, and how does this help us understand guest stars?** Investigation 	 *Stars like the Sun are very hot and transfer energy out toward the Earth. The remnant cloud of gas left over after a guest star event also appears to transfer energy and contain different types of matter than stable stars.*	We consider how studying energy and matter in stable stars, including the Sun, could help us answer our questions about guest stars and form research groups. We are introduced to the *Planning for Obtaining Information Tool* and consider the credibility of sources. We use a new tool called the *Obtaining Information Tool* to keep track of what we find out. We come to consensus around the answers to our research questions and record our ideas in our Progress Trackers and Personal Glossaries. We revisit questions on the DQB. We figure out: • A star is an object that is massive enough to ignite fusion. • Energy from fusion causes stars to emit electromagnetic energy. • Fusion creates new elements as multiple nuclei become one.	

⇓ **Navigation to Next Lesson:** We are wondering about what could happen to cause a stable star to become unstable and possibly become a guest star.

Lesson Question	Phenomena or Design Problem	What we do and figure out	How we represent it
LESSON 4 Lesson Set 1 3 days **How does running out of fuel cause a star to change?** Investigation	 *A model of the balance between the force of gravity and the force from fusion doesn't explain what will happen if there is not sufficient fuel for fusion.*	We model the macro forces of a star to help us figure out what keeps stars stable and make sense of the balance between gravity and pressure in stable stars. We develop research questions and are introduced to a new tool: the *Evaluating Sources of Information Tool*. We gather information and communicate our findings in a gallery tour. We come to consensus on what causes stars to remain stable or become unstable and change and record those ideas in our Progress Trackers. We figure out: • Stars exist because of a feedback loop between gravity forces pushing inward and the outward-pushing forces caused by the energy released by fusion. • Stars, including our Sun, will eventually run out of fuel, and the equilibrium is broken. What happens next depends on the mass of the star and what heavier elements it can fuse. • When a very massive star fuses iron in its core, the star collapses and bounces back in what is called a supernova.	

⇓ **Navigation to Next Lesson:** We will put the pieces together next time to see if we can model and explain the guest stars and if we have answered all our questions yet.

Lesson Question	Phenomena or Design Problem	What we do and figure out	How we represent it
LESSON 5 Lesson Set 1 2 days **Why do some stars seem unchanging, while others appear briefly, change dramatically, and fade away?** Putting Pieces Together	 *A guest star appears and then disappears, but other stars shine with steady light. The cloud left over after a supernova is hotter than the original star and contains different matter.*	We create a Gotta-Have-It Checklist to explain what cause-effect relationships occur within stars. We individually, then collectively, model the feedback loop that keeps stars stable and what happens when this loop is disrupted. We update the Scale Chart and revisit the DQB. We begin to wonder where the stuff for the first stars came from. We figure out: • A guest star is a star that tried to fuse iron in its core, breaking the feedback loop that keeps it stable. • The stable period for a star ranges from a few million years for the most massive to trillions of years for the least massive. • When a super-massive star dies, it collapses and bounces back out, releasing a lot of energy and fusing elements heavier than iron. When this happens, the star in the sky appears very bright. • After this event, the energy will move outward into space, and the star will fade away as the gas begins to disperse into a remnant cloud of heavier elements.	

⇓ **Navigation to Next Lesson:** We figured out that over millions or even billions of years, stars convert lighter elements like hydrogen and helium into heavier and heavier elements. We are wondering how these matter changes could affect the matter in the Universe over time, and we think that by measuring the composition of the whole Universe, we might get some clues.

Lesson Set 2: How has the matter in the Universe changed over time?

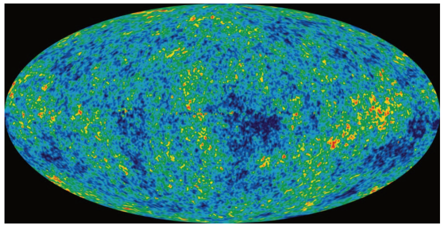
Lesson Question | Phenomena or Design Problem | What we do and figure out | How we represent it

LESSON 6
Lesson Set 2

4 days

How has the matter in the Universe changed over time, and how do we know?

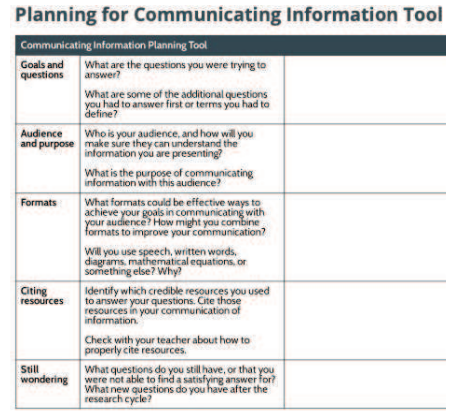
Investigation



When we look at spectra of stars, galaxies, and empty space, we notice puzzling patterns that cannot yet be explained by our model.

We look at spectra of stars, galaxies, and empty space and notice puzzling patterns in each that might hold clues to how the matter in the Universe has changed over time. We are introduced to the [material: PB.L6.HO2] and use all four research tools in small groups to obtain, evaluate, and communicate our ideas. We come to consensus about the evidence we uncovered, which points to an event called the Big Bang, and read about what it means that people call the Big Bang a "theory." Finally, we add to our Progress Trackers and our Personal Glossaries. We figure out:

- The Big Bang theory is supported by evidence.
- Evidence for the Big Bang includes observations of distant galaxies moving away from us, the measured composition of stars, and maps of spectra of the cosmic microwave background, which all match Big Bang models.



Planning for Communicating Information Tool

Communicating Information Planning Tool		
Goals and questions	What are the questions you were trying to answer? What are some of the additional questions you had to answer first or terms you had to define?	
Audience and purpose	Who is your audience, and how will you make sure they can understand the information you are presenting? What is the purpose of communicating information with this audience?	
Formats	What formats could be effective ways to achieve your goals in communicating with your audience? How might you combine formats to improve your communication? Will you use speech, written words, diagrams, mathematical equations, or something else? Why?	
Citing resources	Identify which credible resources you used to answer your questions. Cite those resources in your communication of information. Check with your teacher about how to properly cite resources.	
Still wondering	What questions do you still have, or that you were not able to find a satisfying answer for? What new questions do you have after the research cycle?	

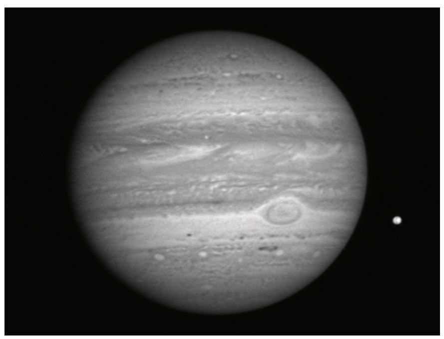
⇓ **Navigation to Next Lesson:** We are ready to wrap up the unit (and the course and the program), and return to our DQB.

LESSON 7
Lesson Set 2

1 day

How can we use the practices and crosscutting concepts we have developed to figure things out on our own?

Putting Pieces Together



We have so many questions about phenomena that we would like to explore in the future.

We consider how the M-E-F triangle frames and our understanding of stability and change help us make sense of our phenomena. We record questions we still want answered on our DQB and then broaden to think about questions we have about other types of phenomena. We reflect on what investigations we can through online research, future science classes, a career in STEM, and/or a lifetime of curiosity. We then engage in a final transfer task. We figure out:

- Stability and change and the M-E-F triangle frames are valuable tools for making sense of our natural world.
- We can use the lenses we have developed and our research tools to continue to investigate our questions outside of class and beyond high school.

⇓ **Navigation to Next Lesson:** There is no next lesson.

LESSONS 1-7
15 days total

TEACHER BACKGROUND KNOWLEDGE

Lab Safety Requirements For Science Investigations

It is important to adopt and follow appropriate safety practices within the context of hands-on investigations and demonstration, whether this is in a traditional science laboratory or in the field. In this way, teachers need to be aware of any school or district safety policies, legal safety standards, and better professional practices that are applicable to hands-on science activities being undertaken.

Science safety practices in laboratories or classrooms require engineering controls and personal protective equipment (e.g., wearing safety goggles, non-latex aprons and gloves, eyewash/shower station, fume hood, and fire extinguishers). Science investigations should always be directly supervised by qualified adults, and safety procedures should be reviewed annually prior to initiating any hands-on activities or demonstration. Prior to each investigation, students should also be reminded specifically of the safety procedures that need to be followed. Each of the lessons within the OpenSciEd units include teacher guidelines for applicable safety procedures for setting up and running an investigation, as well as taking down, disposing of, and storing materials.

Prior to the first science investigation of the year, a safety acknowledgement form for students and parents or guardians should be provided and signed. You can access a model safety acknowledgement form for middle school activities at the following location: http://static.nsta.org/pdfs/SafetyAcknowledgmentForm-MiddleSchool.pdf

Disclaimer: The safety precautions of each activity are based in part on use of the specifically recommended materials and instructions, legal safety standards, and better professional safety practices. Be aware that the selection of alternative materials or procedures for these activities may jeopardize the level of safety and therefore is at the user's own risk.

Please follow these lab safety recommendations for any lesson with an investigation:

1. Wear safety goggles (specifically, indirectly vented chemical splash goggles), a non-latex apron, and non-latex gloves during the set-up, hands-on investigation, and take-down segments of the activity.
2. Immediately wipe up any spilled water and/or granules on the floor, as this is a slip and fall hazard.
3. Follow your Teacher Guide for instructions on disposing of waste materials and/or storage of materials.
4. Secure loose clothing, remove loose jewelry, wear closed-toe shoes, and tie back long hair.
5. Wash your hands with soap and water immediately after completing this activity.
6. Never eat any food items used in a lab activity.
7. Never taste any substance or chemical in the lab.

Specific safety precautions are called out within the lesson using this icon and a call-out box.

Where does this unit fall within the OpenSciEd Scope and Sequence?

This unit is the last in the OpenSciEd High School Physics course sequence and is designed to transition students out of K-12 science into the practices that they might engage with in their everyday life to figure things out, answer questions, and solve problems. It is designed to build on student ideas about energy transfer, unbalanced forces, and matter changes from the first five units of the course. In the first unit of OpenSciEd HS Physics, students developed ideas around energy transfer and conservation in the context of charged particles (electrons) colliding with other electrons (electricity) to transfer energy across great distances. In the second unit of the course, Earth science phenomena that transfer energy differently across scales of time and space motivated the need for forces to explain our observations. In the third unit, students developed a more robust understanding of forces as vectors and used conservation of momentum to make predictions about the outcomes of collisions. In the fourth unit, students expanded their model of forces to include forces of gravity at great distances, using ideas about fields developed in the first unit to understand the relationships between gravity and energy transfer. In the fifth unit, students use energy transfer, electromagnetism, wave mechanics, and forces at a distance to explain how food heats up in a microwave and if/how this technology might be dangerous for humans. In this unit, the final unit of the course, students will explore stars and cosmology, applying ideas about forces and energy from all five previous units on the largest scales.

What is the anchoring phenomenon and why was it chosen?

This unit is anchored by historical accounts of stars that suddenly appear and then disappear a short time later. Students wonder about how some stars appear unchanging, while these stars change so drastically within such a short period of time. That gets students wondering about why stars shine and what could cause stars to change. They organize their questions in terms of matter, energy, and forces and decide to look more closely at the places in the sky where these historical events took place using modern technology. Students will come to figure out that these events are most likely supernovae, powerful explosions that signal the death of a massive star.

The supernovae phenomenon was chosen from a group of phenomena aligned with the target performance expectations based on the results of a survey administered to almost 1,000 students from across the country and in consultation with external advisory panels that include teachers, subject matter experts, and state science administrators. This phenomenon is aligned with space science content, pointing to complex cutting-edge questions about the nature of the Universe. The full physics course is designed to purposefully highlight a variety of different types of phenomena. While we design to privilege the interests of students to whom we owe an educational debt, we must not essentialize minoritized groups by assuming that a trend in the data equates to homogenous interests and experiences. Providing a diverse suite of entry points into content and practices creates more opportunities for every student to connect with the content.

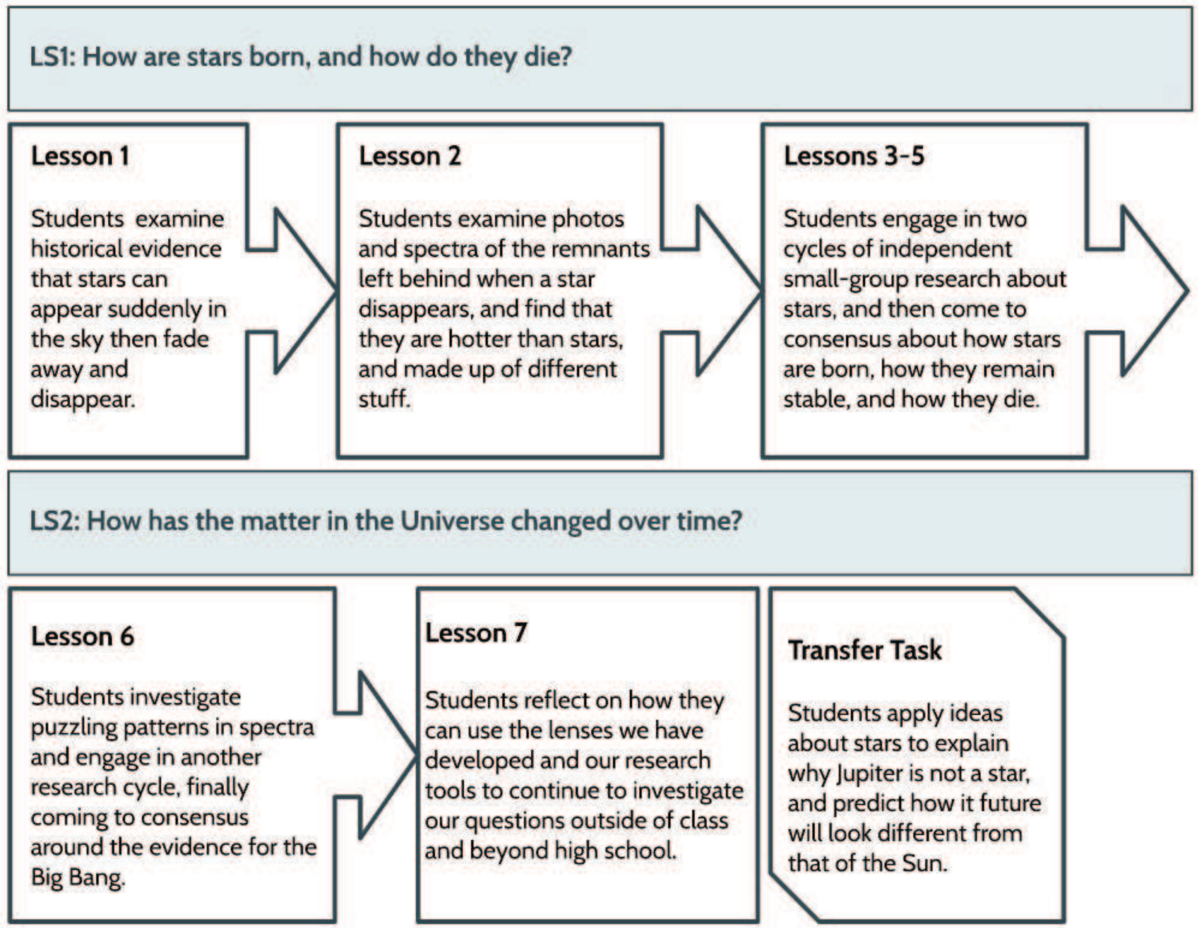
The supernovae phenomenon was chosen for the following reasons:

- Students showed high interest across all demographic groups in explaining these events on the survey.
- To provide a diverse suite of entry points across the course, we were seeking a phenomenon that allowed students to consider abstract, cutting-edge science concepts in a context that is grounded in observations from Earth.
- Teachers and administrators saw the phenomenon as interesting and on grade band.
- Explaining the phenomenon requires the use of Earth and space science concepts and physical science frames.
- Explaining the phenomenon addresses all the DCIs in the bundle at a high school level.
- The phenomenon is complex enough to sustain student research on the internet without students feeling like one search answers the question.

How is the unit structured?

The unit is organized into two main lesson sets. In **Lesson Set 1** (Lessons 2-5)**,** students investigate the question: *How are stars born, and how do they die?* Students investigate photos and spectra of the remnants of these events and then develop two sets of research questions to investigate in small groups. One round focuses on the matter and energy in stars and one round on the forces that are balanced within stars. Then students come to consensus in Lesson 5, modeling the feedback loop that maintains stability over most of the lifecycle of stars and what happens when the feedback loop is disrupted. Students' small-group internet research is scaffolded by a set of tools that are introduced strategically across the lesson set: the *Planning for Obtaining Information Tool*, the *Obtaining Information Tool*, the *Evaluating Online Sources Overview*, and the *Evaluating Sources of Information Tool*. Students figure out that over millions or even billions of years, stars convert lighter elements like hydrogen and helium into heavier and heavier elements, and this motivates the next lesson set, as students wonder where these elements came from and how these matter changes could affect the matter in the Universe over time.

In **Lesson Set 2** (Lessons 6-7), students investigate the question: *How has the matter in the Universe changed over time?* Students follow clues from spectra of the Universe to engage in a third internet research cycle, using the tools from Lesson Set 1, as well as a new one, the *Planning for Communicating Information Tool*. Using their research, they come to consensus around evidence for a hot dense Universe 14 billion years ago that has expanded into what we see today, a theory known as the Big Bang. Lesson 7 is intended to be the last lesson of the unit and the OpenSciEd High School Physics course and thus the last lesson of the OpenSciEd K-12 program. The lesson is designed to help students think metacognitively about the practices they have developed over the OpenSciEd High School program for asking and answering science questions and the crosscutting conceptual frames they can apply to help them make sense of what they figure out. They develop Driving Questions that they will not be able to answer in class but that students are encouraged to pursue answers to through independent online research, future science classes, a career in STEM, and/or a lifetime of curiosity.



What elements of the NGSS three dimensions are developed in this unit?

Disciplinary Core Ideas are reproduced verbatim from *A Framework for K-12 Science Education: Practices, Crosscutting Concepts, and Core Ideas*, DOI: https://doi.org/10.17226/13165, National Research Council, Division of Behavioral and Social Sciences and Education, Board on Science Education, Committee on a Conceptual Framework for New K-12 Science Education Standards, National Academies Press, Washington, DC. This material may be reproduced and used by other parties with this attribution. If the original material is altered in any way, the attribution must state that the material is adapted from the original.

This unit is designed to introduce students to ideas about stellar life cycles and cosmology while transitioning them out of the OpenSciEd High School program and into the rest of their lives, where we hope that they will continue to be curious and use science to figure things out and solve problems. To this end, obtaining, evaluating, and communicating information **is intentionally developed** across the unit through a scaffolded series of linked tools that support strategies that students can continue to use independently when the course is over. These include the *Planning for Obtaining Information Tool*, *Obtaining Information Tool*, *Evaluating Online Sources Overview* and *Evaluating Sources of Information Tool*, and *Planning for Communicating Information Tool.* In Lesson 3, students complete their first research cycle to determine how **fusion makes stars shine** using the *Planning for Obtaining Information Tool*, and a scaffolded version of the *Obtaining Information Tool* where URLs to resources are explicitly provided.

The idea of balance and imbalance is fundamental to explaining stellar and cosmological phenomena, thus **stability and change** is **intentionally developed** across the unit through explicit prompts. In Lesson 4, students complete their second research cycle with the addition of the *Obtaining Information Tool* and *Evaluating Online Sources Overview* and the scaffolding removed from the *Obtaining Information Tool.* From this research cycle, students determine how stars remain stable and when they become unstable, sometimes resulting in **supernovae**, which prepares them to explain the guest stars in Lesson 5. In Lesson 6, students follow clues from spectra of the Universe to engage in a third internet research cycle using the tools from previous cycles, as well the *Planning for Communicating Information Tool*. Then they come to consensus around **evidence for a hot dense Universe 14 billion years ago that has expanded into what we see today, a theory known as the Big Bang**.

While not intentionally developed, **asking questions and defining problems** is **key to the sensemaking** in this unit, as students develop their own research questions both in the context of the unit and in Lesson 7 as they look forward to the rest of their lives. **Key to the sensemaking** is also **developing and using models** as students make sense of their research through individual and consensus modeling of **fusion and star systems**. In order to move fluidly between **atomic and stellar scales**, **scale, proportion and quantity** is also **key to the sensemakin**g in the unit. **Energy and matter** is **key to the sensemaking** as well, structured through the use of the M-E-F triangle conceptual framework as part of the DQB and students' research in Lessons 3 and 4. **Engaging in argument from evidence** and **patterns** are also **key to the sensemaking** in select lessons.

This unit builds toward these performance expectations:
HS-ESS1-1 Develop a model based on evidence to illustrate the life span of the Sun and the role of nuclear fusion in the Sun's core to release energy that eventually reaches Earth in the form of radiation. **HS-ESS1-3** Communicate scientific ideas about the way stars, over their life cycle, produce elements. **HS-ESS1-2✝** Construct an explanation of the Big Bang theory based on astronomical evidence of light spectra, motion of distant galaxies, and composition of matter in the Universe. **HS-PS1-8✝** Develop models to illustrate the ~~changes in the composition of the nucleus of the atom~~ and the energy released during the processes of ~~fission,~~ fusion, ~~and radioactive decay.~~

*This performance expectation is developed across multiple units. This unit reinforces these NGSS PEs in a physics context.
✝This performance expectation is developed across multiple courses. This unit reinforces or works toward these NGSS PEs that students will have previously developed in the OpenSciEd chemistry and/or biology courses.

Science and Engineering Practices	Disciplinary Core Ideas*	Crosscutting Concepts

Obtaining, Evaluating, and Communicating Information Obtaining, evaluating, and communicating information in 9–12 builds on K–8 experiences and progresses to evaluating the validity and reliability of the claims, methods, and designs. The following elements of this practice are intentionally developed across this unit: • **8.2** Compare, integrate, and evaluate sources of information presented in different media or formats (e.g., visually, quantitatively) as well as in words in order to address a scientific question or solve a problem. • **8.3** Gather, read, and evaluate scientific and/or technical information from multiple authoritative sources, assessing the evidence and usefulness of each source. • **8.5** Communicate scientific and/or technical information or ideas (e.g., about phenomena and/or the process of development and the design and performance of a proposed process or system) in multiple formats (i.e., orally, graphically, textually, mathematically). Elements from the following practices are also **key to the sensemaking** in this unit: • Asking questions and defining problems • Developing and using models • Engaging in argument from evidence	**ESS1.A: The Universe and Its Stars** • The star called the Sun is changing and will burn out over a lifespan of approximately 10 billion years. (HS-ESS1-1) • The study of stars' light spectra and brightness is used to identify compositional elements of stars, their movements, and their distances from Earth. (HS-ESS1-2),(HS-ESS1-3) • The Big Bang theory is supported by observations of distant galaxies receding from our own, of the measured composition of stars and non-stellar gasses, and of the maps of spectra of the primordial radiation (cosmic microwave background) that still fills the Universe. (HS-ESS1-2) • Other than the hydrogen and helium formed at the time of the Big Bang, nuclear fusion within stars produces all atomic nuclei lighter than and including iron, and the process releases electromagnetic energy. Heavier elements are produced when certain massive stars achieve a supernova stage and explode. (HS-ESS1- 2), (HS-ESS1-3) **PS1.C: Nuclear Processes** • Nuclear processes, including fusion~~, fission, and radioactive decays of unstable nuclei~~, involve release or absorption of energy. The total number of neutrons plus protons does not change in any nuclear process. **PS3.D: Energy in Chemical Processes and Everyday Life** • Nuclear fusion processes in the center of the Sun release the energy that ultimately reaches Earth as radiation. (secondary to HS-ESS1-1) **PS4.B: Electromagnetic Radiation** • Atoms of each element emit ~~and absorb~~ characteristic frequencies of light. ~~These characteristics allow identification of the presence of an element, even in microscopic quantities.~~ This DCI is associated with a performance expectation that is not included in the bundle for this unit (HS-ESS1-2), and is addressed in OpenSciEd Chemistry.	**Stability and Change.** For both designed and natural systems, conditions that affect stability and factors that control rates of change are critical elements to consider and understand. • **7.1** Much of science deals with constructing explanations of how things change and how they remain stable. • **7.3** Feedback (negative or positive) can stabilize or destabilize a system. Elements from the following crosscutting concepts are also **key to the sensemaking** in this unit: • Patterns • Scale, Proportion, and Quantity • Energy and Matter

Connections to the Nature (NOS) of Science

Connections to the Nature of Science (NOS)	
Which elements of NOS are developed in the unit?	How are they developed?

Science Models, Laws, Mechanisms, and Theories Explain Natural Phenomena: A scientific theory is a substantiated explanation of some aspect of the natural world based on a body of facts that has been repeatedly confirmed through observation and experiment, and the science community validates each theory before it is accepted. If new evidence is discovered that the theory does not accommodate, the theory is generally modified in light of this new evidence.	Lesson 6 gives students the opportunity to read about and reflect on connections to the Nature of Science. One of these is the nature of theory. Students read about why the Big Bang is sometimes called a theory and what that means in the context of science.
Science is a Way of Knowing: Science knowledge has a history that includes the refinement of, and changes to, theories, ideas, and beliefs over time.	In Lesson 1, students learn about the history of supernova observations across cultures and read about how Kepler's ideas about supernovae were rooted in his observations, and thus scientific, but ultimately also wrong. Students also learn about how recent developments like the telescope have changed the types of questions scientists are able to ask and how they go about answering them. Lesson 6 gives students the opportunity to read about and reflect on connections to the Nature of Science. One of these is the nature of theory. Students read about why the Big Bang is sometimes called a theory and how it has been refined through discoveries like the redshift of galaxies by Hubble and the cosmic microwave background (CMB) by Penzias and Wilson.
Science is a Human Endeavor: Scientific knowledge is a result of human endeavor, imagination, and creativity.	Lesson 6 students read about the discovery of the cosmic microwave background (CMB) by Penzias and Wilson, a triumph of human creativity and elimination of alternative sources (at first they thought the CMB was caused by pigeon droppings). In addition, in Lesson 7, students are encouraged to be reflective about how they might use tools from this class to pursue answers to their scientific questions through online research, future science classes, or through a career in STEM.

How does the unit build three-dimensional progressions across the course and the program?

This unit uses and builds upon **Disciplinary Core Ideas (DCIs)** and other science ideas that students should have previously developed in the **OpenSciEd High School Biology and Chemistry courses** and previous units in **this physics course.**

- Nuclear processes conserve nuclear particles but can produce new types of matter. (*OpenSciEd Unit B.1: How do ecosystems work, and how can understanding them help us protect them? (Serengeti Unit)*, *OpenSciEd Unit C.1: How can we slow the flow of energy on Earth to protect vulnerable coastal communities? (Polar Ice Unit)*, *OpenSciEd Unit C.5: How can chemistry help us evaluate fuels and transportation options to benefit the Earth and our communities? (Fuels Unit)*, and *OpenSciEd Unit P.2: How forces in Earth's interior determine what will happen to its surface? (Earth's Interior Unit)*)
- Like particles repel one another through electric forces. (*OpenSciEd Unit C.2: What causes lightning and why are some places safer than others when it strikes? (Electrostatics Unit)*, *OpenSciEd Unit P.5: How do we use radiation in our lives and is it safe for humans? (Microwave Unit)*)
- Light is electromagnetic radiation, which is modeled either as oscillating electric and magnetic fields moving through space or as particles called photons.(*OpenSciEd Unit P.5: How do we use radiation in our lives and is it safe for humans? (Microwave Unit)*)
- Energy can be transferred into and out of and stored in magnetic and electric fields. (*OpenSciEd Unit C.2: What causes lightning and why are some places safer than others when it strikes? (Electrostatics Unit)*, *OpenSciEd Unit C.5: How can chemistry help us evaluate fuels and transportation options to benefit the Earth and our communities? (Fuels Unit)*)
- The Universe is organized by the force of gravity, which acts between any two objects and is dependent on both their masses and the distance between them. (*OpenSciEd Unit P.4: Meteors, Orbits, and Gravity (Meteors Unit)*)

This unit also reinforces and builds from the following **DCI elements** from the **OpenSciEd Middle School sequence**.

- Stars are very far away, so the light we see from them has traveled a long time. (*OpenSciEd Unit 8.3: How can a magnet move another object without touching it? (Magnets Unit)*)
- Our galaxy is one of many, many galaxies that make up our Universe. (*OpenSciEd Unit 8.3: How can a magnet move another object without touching it? (Magnets Unit)*)

This unit uses and builds upon high school level **Science and Engineering Practices (SEPs)** and **Crosscutting Concepts (CCCs)** that students should have previously developed in **OpenSciEd High School Biology and Chemistry**. The progression of these practices and concepts across the program are as follows:

	Questions	Models	Investigations	Data	Math	Explanation	Argument	Obtaining

Biology	*Cancer Unit*	*Serengeti Unit, Fires Unit*	*Fires Unit, Natural Selection Unit*	*Natural Selection Unit, Cancer Unit*	*Serengeti Unit*	*Fires Unit, Cancer Unit, Natural Selection Unit*	*Speciation Unit*	*Cancer Unit, Speciation Unit*
Chemistry	*Polar Ice Unit*	*Electrostatics Unit, Space Survival Unit, Oysters Unit*	*Polar Ice Unit*	*Fuels Unit*	*Polar Ice Unit*	*Fuels Unit*	*Oysters Unit, Fuels Unit*	*Electrostatics Unit, Space Survival Unit*
Physics	*Electricity Unit, Cosmology Unit*	*Electricity Unit, Microwave Unit*	*Microwave Unit*	*Electricity Unit, Earth's Interior Unit, Vehicle Collisions Unit, Meteors Unit*	*Vehicle Collisions Unit, Meteors Unit*	*Electricity Unit, Earth's Interior Unit, Vehicle Collisions Unit*	*Vehicle Collisions Unit*	*Cosmology Unit, Microwave Unit*

	Patterns	Cause/Effect	Scale	Systems/Models	Energy/Matter	Structure/Function	Stability/Change
Biology	*Natural Selection Unit, Speciation Unit*	*Cancer Unit, Natural Selection Unit, Speciation Unit, Serengeti Unit*	*Serengeti Unit*	*Fires Unit, Cancer Unit, Serengeti Unit*	*Fires Unit, Serengeti Unit*	*Cancer Unit*	*Speciation Unit, Serengeti Unit*
Chemistry	*Electrostatics Unit, Space Survival Unit*	*Electrostatics Unit, Oysters Unit*	*Oysters Unit*	*Polar Ice Unit*	*Polar Ice Unit, Fuels Unit*	*Space Survival Unit*	*Oysters Unit, Fuels Unit*
Physics	*Cosmology Unit, Vehicle Collisions Unit, Earth's Interior Unit*	*Vehicle Collisions Unit, Earth's Interior Unit*	*Meteors Unit, Earth's Interior Unit*	*Electricity Unit, Vehicle Collisions Unit, Microwave Unit*	*Electricity Unit, Earth's Interior Unit*	*Earth's Interior Unit, Vehicle Collisions Unit*	*Electricity Unit, Cosmology Unit*

In particular, this unit intentionally develops Practice 8 from the NGSS: Obtaining, Evaluating and Communicating Information, building on a progression across the course:

- In *OpenSciEd Unit P.1: How can we design more reliable systems to meet our communities' energy needs? (Electricity Unit)*, students are reading material prepared for them using protocols.
- In *OpenSciEd Unit P.4: Meteors, Orbits, and Gravity (Meteors Unit)*, students use the internet to answer questions in the anchor and continue to do readings.
- In *OpenSciEd Unit P.5: How do we use radiation in our lives and is it safe for humans? (Microwave Unit)*, students evaluate the validity and reliability of information within texts.

What are some common ideas that students might have?

Students will come into the unit with many ideas about energy derived from previous classroom experiences, intuitive understandings of the way the world works, everyday experiences with movement, and the conversations they have had with parents, friends, and family members.

Some relevant ideas that students may come into the unit with include the following:

1. The Sun is on fire.
2. The Sun moves around the Earth (please don't judge - many people still use this model, however unconsciously, when making sense of the world).
3. The Earth is the largest thing in the Universe.
4. The Universe consists of our Solar System, and/or the Milky Way, and all the stars are embedded in/around the Solar System.
5. The Universe consists of our galaxy, and/or the Sun is at the center of the galaxy.
6. All stars (including our Sun) will someday supernova and become black holes.
7. Black holes are dangerous and could suck matter in from far away.
8. We can observe events in space as they happen in real time.
9. We have sent probes to other stars, and even other galaxies, and taken photos of our own galaxy from above.

10. Stars never change; they are constant both in terms of their locations and their characteristics.
11. The Big Bang is a theory about the origin/cause/purpose of the Universe and invalidates traditional cosmologies.
12. The Big Bang was an explosion emanating from a single point.
13. The Universe is expanding "into" something.
14. The Universe cannot be expanding faster than the speed of light.

It is valuable to think of ideas like these not as misconceptions that need to be erased but as productive ideas that we can use to build understanding, much like a model or a hypothesis. Not only does this help some students feel more comfortable talking about science and build a scientific identity, it improves science learning across the board. For example, the model of the Big Bang as a rapidly expanding sphere from a single point is limited, and many educators label it as a "misconception." But this model is very valuable for conceptualizing the history of the Universe and is often invoked by scientists to explain observable phenomena like the cosmic microwave background.

How will I need to modify the unit if taught out of sequence?

This is the last unit of the High School Physics Course in the OpenSciEd Scope and Sequence. Given this placement, several modifications would need to be made if teaching physics first or teaching this unit earlier in the Physics course. These include the following adjustments:

- If taught before OpenSciEd High School Chemistry, supplemental teaching of the particle model of matter will be required, including conceptual understanding of spectral analysis, the nature of electrons, nuclei, and atoms.
- If taught earlier in the school year, additional supplementary materials related to energy, forces, and matter, including development of the M-E-F triangle conceptual framework should be incorporated into class discussions to help students integrate a forces and energy perspective. A visual of this conceptual framework is included in Lesson 1. Additional supplementary teaching about the nature of electromagnetic radiation may also be required. Please see Lesson 3 of *OpenSciEd Unit P.2: How forces in Earth's interior determine what will happen to its surface? (Earth's Interior Unit)* for instructions on how to co-develop the M-E-F triangle as a conceptual tool.
- If taught before *OpenSciEd Unit P.2: How forces in Earth's interior determine what will happen to its surface? (Earth's Interior Unit)*, additional supplementary materials related to scale and stability and change will be required. This unit uses the Scale Chart conceptual tool developed in *OpenSciEd Unit P.2: How forces in Earth's interior determine what will happen to its surface? (Earth's Interior Unit)* in order to help students think about the significance of scale and how systems can seem stable at one scale but not at another.

How do I shorten or condense the unit if needed? How can I extend the unit if needed?

This unit is already very condensed, spanning only 15 days. The following are example options to shorten or condense parts of the unit without eliminating important sensemaking for students:

- If you only need to develop disciplinary core ideas related to stars, you can end the unit after Lesson 5. We recommend that if you do this, you introduce the *Planning for Communicating Information Tool* currently in Lesson 6 in Lesson 4. You can still do Lesson 7 to complete the unit, including the transfer task, which does not focus on Big Bang related content from Lesson 6. This option will cut four days from the unit.

To extend or enhance the unit, consider the following:

- Give students more time to conduct their research in Lessons 3, 4, and 6.
- Pursue additional DQB questions as a fourth research cycle between Lessons 6 and 7.

What mathematics concepts will students engage with in the unit?

This unit does not rely on high school level mathematics concepts. Students will be doing research on the internet. Depending on what they choose to investigate in more depth, they may unearth equations such as $E=mc^2$, but they will not be required to solve any equations as part of the unit.

What strategies are available to support equitable science learning in this unit?

OpenSciEd units are designed to promote equitable access to high-quality science learning experiences for all students. Each unit includes strategies that are integrated throughout the OpenSciEd routines and are intended to increase relevance and provide access to science learning for all students. OpenSciEd units support these equity goals through several specific strategies such as: 1) integrating Universal Design for Learning (UDL) Principles during the unit design process to reduce potential barriers and increase accessibility for students to engage in learning experiences; 2) developing and supporting classroom agreements that encourage a safe learning culture; 3) supporting classroom discourse to promote students in developing, sharing, and revising their ideas; and 4) specific strategies for supporting emerging multilingual students in science classrooms.

Many of these strategies are highlighted in the Teacher Guides in sidebar callout boxes with the headings of:

- Attending to Equity
- Supporting Emerging Multilingual Learners
- Supporting Universal Design for Learning
- Additional Guidance

- Alternate Activity
- Key Ideas
- Discussion Callouts

What are recommended adult-level learning resources for the science concepts in this unit?

The OpenSciEd instructional model focuses on the teacher being a member of the classroom community, supporting students in figuring out scientific ideas motivated by their questions about phenomena. Students iteratively build their understanding of phenomena as the unit unfolds. To match the incremental build of a full scientific explanation across the unit, the science content background necessary for you to teach individual lessons incrementally builds too. Throughout the unit, we provide just-in-time science content background for you that is specific to the Disciplinary Core Ideas (DCIs) that will be figured out in a lesson. Places to look for this guidance include the “Where we are going” and “Where we are not going” sections for each lesson. Also, the expected student responses, keys, and rubrics illustrate important science ideas that should be developed in each lesson. The K-12 Science Framework is another great resource to learn more about the DCIs in this unit (**ESS1.A: The Universe and Its Stars, PS1.C: Nuclear Processes, PS3.D: Energy in Chemical Processes and Everyday Life**), including what students have learned previously and where they are headed in high school. In addition to the science content background information embedded in the lesson resources, below we provide recommended resources that can help build your understanding of phenomena and Performance Expectations bundle for this unit:

- To learn more about historical supernovae:
  - **The Historical Supernovae (out-of-print book, easily available at used book stores)**: Clark, D. H.; Stephenson, F. R. (June 29, 1981). "The Historical Supernovae". Supernovae: A survey of current research; Proceedings of the Advanced Study Institute. Cambridge, England: Dordrecht, D. Reidel Publishing Co.
  - **7-Naked Eye Supernovae Throughout Human History (Astronomy Magazine article):** https://astronomy.com/news/2020/11/7-naked-eye-supernovae-throughout-human-history
  - **Blasts from the Past: Historical Supernovas (Infographic from NASA/Chandra X-ray Observatory)**: https://chandra.harvard.edu/resources/handouts/lithos/hist_remnants.pdf
- To learn more about stellar evolution:
  - **What Happens If A Star Explodes Near The Earth? (Veratiserum video about supernovae):** https://www.youtube.com/watch?v=evUfG3lrk5U
  - **Introduction to the Hertzsprung-Russell diagram (from Australia Telescope National Facility):** https://www.atnf.csiro.au/outreach/education/senior/astrophysics/stellarevolution_hrintro.html
- To learn more about the evidence for the Big Bang:
  - **Evidence for the Big Bang Theory (PBS NOVA short video exploring the cosmic microwave background (CMB))**: http://www.pbslearningmedia.org/resource/ess05.sci.ess.eiu.microwave/evidence-for-the-big-bang-theory/
  - **Misconceptions about the Universe (Veritaserum video about the size of the Universe and rate of expansion):** https://youtu.be/XBr4GkRnYO4
  - **Big Bang Discovery (Naked Science video about the discovery of the CMB and what that means)**: https://www.youtube.com/watch?v=-k5bROJH_5k
- To learn more about current best practices for media literacy:
  - **Media Literacy Now resource library**: https://medialiteracynow.org/resource-library/

Guidance for Developing Your Personal Glossaries

This unit refers to two categories of academic language (i.e., vocabulary). Most often in this unit, students will have experiences with and discussions about science ideas before they know the specific vocabulary word that names that idea. After students have developed a deep understanding of a science idea through these experiences, and sometimes because they are looking for a more efficient way to express that idea, they have co-developed that definition and can add the specific term to a Personal Glossary at the back of their notebooks. These “definitions we co-develop” should be recorded using the students’ own words whenever possible. On the other hand, “definitions we encounter” are “given” to students in the course of a reading, video, or other activity, often with a definition clearly stated in the text. Sometimes, definitions we encounter are helpful just in that lesson and need not be recorded in students’ Personal Glossaries. However, if a word we encounter will be frequently referred to throughout the unit, it should be added.

It is best for students if you create consensus definitions in the moment, using phrases and pictorial representations that the class develops together as they discuss their experiences in the lesson. When they co-create the meaning of the word, students “own” the word—it honors their use of language and connects their specific experiences to the vocabulary of science beyond their classroom. It is especially important for emergent multilingual students to have a reference for this important vocabulary, which includes an accessible definition and visual support. Sometimes defining a word is a challenge. The *Teacher Guide* provides a suggested definition for each term to support you in helping your class develop a student-friendly definition that is also scientifically accurate.

The definitions we co-develop and encounter in this unit are listed in this document and in each lesson to help prepare and to avoid introducing a word before students have earned it. They are not intended as a vocabulary list for students to study before a lesson, as that would undermine the authentic and lasting connection students can make with these words when they are allowed to experience them first as ideas they’re trying to figure out. Some lessons include built-in opportunities for students to add to their Personal Glossaries, but some do not. Offer this opportunity whenever students feel they have co-constructed a definition and it would be helpful to keep track of it, and encourage students to keep track of words from previous lessons that have become useful in addition to new words.

Lesson	Words and equations with meanings we co-construct	Words and equations with meanings we encounter
L1		*remnant*
L2		*spectroscopy, absorption lines*
L3		*fusion, hydrogen, credibility, additional words from student research*
L4		*supernova, equilibrium, feedback loop, additional words from student research*
L5	*supernova, feedback loop, equilibrium, hydrogen, remnant, exothermic, endothermic*	
L6	*Big Bang, nucleogenesis, cosmic microwave background*	*additional words from student research*
L7		

HOME COMMUNICATION

Dear Parents, Guardians, and Care-Givers,

Your child's high school physics class is starting a unit called *Why do stars shine and will they shine forever?* as part of the OpenSciEd high school science curriculum. This unit is anchored by historical accounts of stars that suddenly appear and then disappear a short time later. Students wonder about how some stars appear unchanging, while these stars change so drastically within such a short period of time. That gets students wondering about why stars shine and what could cause stars to change.

Be aware that your student will be doing research on the internet as part of this unit. They will be provided with scaffolds and support to help them find reliable resources for their research.

Helping your student make sense of their learning

- There is no need to teach your student any related vocabulary before the unit because many words have multiple meanings and new terms are often easier to remember once students have had some experience with them.
- Encourage your student to expand their thinking by asking them to give you examples or to say more about their ideas.
- Ask how your student arrived at a particular conclusion.
- Ask your student to recall what other students have said in class and what about those ideas they agreed or disagreed with.
- Repeat, rephrase, or paraphrase what your student says as a way to clarify their ideas.

Having conversations about science

- Encourage your student's curiosity through talking about their noticings and wonderings.
- Ask your student to explain why most stars appear not to change in the sky, and why some change very rapidly.
- Ask your student to explain what evidence we have for an expanding universe.

This unit is intended to be the last of the OpenSciEd High School Physics course, and thus the last lesson of the OpenSciEd K-12 program. The unit is designed to help students think metacognitively about the practices they have developed over the OpenSciEd High School program for asking and answering science questions, and the frames they can apply to help them make sense of what they figure out. They develop questions that they will not be able to answer in class, but that students are encouraged to pursue answers to through independent online research, future science classes, a career in STEM, and/or a lifetime of curiosity.

Best,

Querido guardián,

La clase de física de la escuela secundaria de su hijo está comenzando una unidad llamada *¿Por qué brillan las estrellas y brillarán para siempre?* como parte del plan de estudios de ciencias de la escuela secundaria OpenSciEd. Esta unidad se basa en relatos históricos de estrellas que aparecen repentinamente y desaparecen poco tiempo después. Los estudiantes se preguntan cómo algunas estrellas parecen inmutables, mientras que cambian tan drásticamente en un período de tiempo tan corto. Esto hace que los estudiantes se pregunten por qué las estrellas brillan y qué podría causar que las estrellas cambien.

Tenga en cuenta que su estudiante investigará en Internet como parte de esta unidad. Se les proporcionará apoyo y apoyo para ayudarles a encontrar recursos confiables para su investigación.

Ayudar a su estudiante a hacer sentido de su aprendizaje

- No es necesario enseñarle a su estudiante ningún vocabulario relacionado antes de la unidad porque muchas palabras tienen múltiples significados y los términos nuevos suelen ser más fáciles de recordar una vez que los estudiantes han tenido algo de experiencia con ellos.
- Anime a su estudiante a ampliar su pensamiento pidiéndole que le dé ejemplos o que diga más sobre sus ideas.
- Pregunte cómo llegó su estudiante a una conclusión particular.
- Pídale a su estudiante que recuerde lo que otros estudiantes han dicho en clase y qué pasa con las ideas con las que estuvo de acuerdo o en desacuerdo.
- Repita, reformule o parafrasee lo que dice su hijo como una forma de aclarar sus ideas.

Tener conversaciones sobre ciencias

- Fomente la curiosidad de su estudiante hablando sobre sus observaciones y dudas.
- Pídale a su hijo que explique por qué la mayoría de las estrellas parecen no cambiar en el cielo y por qué algunas cambian muy rápidamente.
- Pídale a su hijo que explique qué evidencia tenemos de un universo en expansión.

Esta unidad está destinada a ser la última del curso de Física de OpenSciEd High School y, por lo tanto, la última lección del programa OpenSciEd K-12. La unidad está diseñada para ayudar a los estudiantes a pensar metacognitivamente sobre las prácticas que han desarrollado durante el programa OpenSciEd High School para hacer y responder preguntas científicas, y los marcos que pueden aplicar para ayudarlos a dar sentido a lo que descubren. Desarrollan preguntas que no podrán responder en clase, pero que se anima a los estudiantes a buscar respuestas a través de investigaciones independientes en línea, futuras clases de ciencias, una carrera en STEM y/o una vida de curiosidad.

Sinceramente,

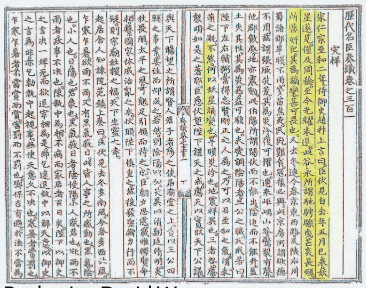
LESSON 1: Why do some stars seem unchanging, while others appear briefly, change dramatically, and fade away?

PREVIOUS LESSON *There is no previous lesson.*

THIS LESSON

ANCHORING PHENOMENON

2 days



Pankenier, David W.

We examine historical evidence that some stars appear in the night sky even though we could not see a star there previously. The star fades away and seems to disappear. This has also happened as recently as 1987. We map these events on a star map and look for patterns. We wonder what is happening to these stars and want to look at places in the sky where this has happened.

NEXT LESSON *We will compare photos of the parts of the sky where some of these guest star events were observed and notice remnants of what looks like gas or dust. We will analyze spectra to determine the composition of the matter that these remnants are made of and its temperature. We will compare these to the spectra of stable stars and add to our Progress Trackers. We will ask new questions and add them to our Driving Question Board.*

BUILDING TOWARD NGSS

HS-ESS1-1, HS-ESS1-2, HS-ESS1-3, HS-PS1-8

WHAT STUDENTS WILL DO

1.A Develop system models (or sets of models) to explain why the stars we see at night appear stable over time, while historical accounts of guest stars describe them changing dramatically. (SEP: 2.3; CCC: 7.1; DCI: ESS1.A.1)

1.B Ask questions that arise from historical observations of dramatic changes in the brightness, shape, and color of stars to clarify our models, and seek additional information. (SEP: 1.1, 1.4; CCC: 7.1; DCI: ESS1.A.2)

WHAT STUDENTS WILL FIGURE OUT

- A guest star is a star that appears and then seems to disappear a short time later.
- Guest stars are distributed across the sky but seem to be concentrated along the plane of our galaxy (the Milky Way).

Lesson 1 • Learning Plan Snapshot

Part	Duration		Summary	Slide	Materials
1	12 min		**INTRODUCE A NEW PHENOMENON** Present information about the guest star of 1054. Map the star on the laminated star map.	A-F	*Guest Star 1054 Location* (can reuse across classes), printed star map, sticky dots, chart paper, dry erase markers, world map or globe (optional)
2	15 min		**READ ABOUT OTHER GUEST STARS** Read about a different guest star in small groups and map the star on the star map.	G	*Historical Guest Stars*, M-E-F Triangle poster from previous units
3	10 min		**DISCUSS IN JIGSAW GROUPS** Regroup students into different small groups to discuss evidence that matter is changing, energy is transferring, or forces are unbalanced in each event from the readings. Facilitate an Initial Ideas Discussion to make a public record of our ideas.	H	chart paper, chart paper markers
4	4 min		**KEEP TRACK OF QUESTIONS** Pause for students to record questions that have come up so far in their notebooks.	I	
5	4 min		**NAVIGATE** Introduce home learning.	J	*Stars Home Learning*
					End of day 1
6	4 min		**NAVIGATE**	K-L	
7	5 min		**1987 GUEST STAR DEEP DIVE** Respond to student exit tickets about guest star 1987 and present more information about the star. Map the star on the star map.	M-P	
8	12 min		**INDIVIDUAL MODELING** Facilitate students making two models of changing patterns in the night sky. Students share their models with a partner.	Q-R	
9	10 min		**DEVELOP INITIAL CONSENSUS MODEL** Lead the class in building consensus models of a star and a guest star using ideas from individual models.	S-T	chart paper, chart paper markers
10	8 min		**BUILD THE DQB** Build the DQB using student questions. Allow students to lead this process.	U-V	paper or sticky notes for DQB questions, tape
11	6 min		**NAVIGATE: NEXT STEPS** Brainstorm and chart with the class ideas for investigations and data needed to answer their questions. Motivate the class to look at places in the sky where these events have happened.	W	chart paper, chart paper markers
					End of day 2

Lesson 1 • Materials List

	per student	per group	per class
Lesson materials	• *Guest Star 1054 Location* (can reuse across classes) • printed star map • science notebook • sticky dots • *Historical Guest Stars* • *Stars Home Learning* • paper or sticky notes for DQB questions • tape		• chart paper • dry erase markers • world map or globe (optional) • M-E-F Triangle poster from previous units • chart paper markers

Materials preparation (30 minutes)

Review teacher guide, slides, and teacher references or keys (if applicable).

Make copies of handouts and ensure sufficient copies of student references, readings, and procedures are available.

For day 1:
- Prepare the laminated star map at the front of the classroom. This file is available from the unit kit list and should be printed at a minimum of 11 by 17. A version of it can be found in *Star Map*
- Prepare a chart paper poster titled "M-E-F Evidence." Split it into three stacked boxes for Matter, Energy, and Forces.
- Collect and review Exit Tickets at the end of the day.

For day 2:
- Have 3 pieces of chart paper or poster paper per class available for the class consensus model, the DQB, and Ideas for Investigations/Data.
- Gather 20 pieces of printer or construction paper per class. Cut up paper into roughly 4 slips per page. Students will use these strips of paper to write down their ideas for investigation and tape these slips of paper to the DQB next to related DQB questions. Alternatively, you may use large sticky notes.
- Consider printing out slides M-O for students to annotate during the mini-lecture.

Lesson 1 • Where We Are Going and NOT Going

Where We Are Going

The goal of this lesson is to motivate students to question and wonder about stars. Students should figure out that although we think of stars as very stable, they do change, and that sometimes they seem to appear, get brighter, and then disappear. They will read historical accounts of this phenomenon and will be introduced to one occurrence in recent history. In this way, students will have the opportunity to engage with science as a way of knowing. They learn about historical knowledge across cultures and the refinement of and changes to ideas over time.

Because this is the first lesson in a new unit, the goal is **not** to establish any new science ideas, but rather to get students' prior ideas and experiences on the table. This lesson is an opportunity to pre-assess students' ideas about stable stars and how stars can change. This lesson sets up students to investigate and build ideas around the following disciplinary core ideas:

- **ESS1.A.1** The star ~~called the sun~~ is changing ~~and will burn out over a lifespan of approximately 10 billion years~~. (HS-ESS1-1)

This lesson does not cover specifics of this element, nor does it focus any attention on the Sun and its lifespan. Rather it sets students up to begin thinking about stars and that they change. The connection to the Sun and its lifespan will be made in Lesson 3.

- **ESS1.A.2** The study of stars' light spectra and brightness is used to identify ~~compositional elements of stars~~, their movements, and their distances from Earth. (HS-ESS1- 2),(HS-ESS1-3)

Students begin to ask questions about stars brightness, shape, and color in this lesson. While they do not discuss spectra explicitly here, these ideas may come out if students have taken OpenSciEd HS. Chemistry, or a similar course. Otherwise, ideas about color that are elicited in this lesson will set them up for developing an understanding of stars' light spectra and composition in Lesson 2 and considering the spectra of stars, galaxies, and empty space in Lesson 6.

This lesson also has a strong connection to the nature of science as set out in Appendix H of the NGSS.

- **Science is a Way of Knowing.** Science knowledge has a history that includes the refinement of, and changes to, theories, ideas, and beliefs over time.

Students learn about the writings of contemporary astronomers from around the world about guest stars, many of which required significant refinement over time. For example, students will read and share about Kepler's theory that new matter springs from disorder, which we know to violate the conservation of matter.

This lesson is designed to coherently build on ideas related to the following science and engineering practices:

- **1.1** Ask questions that arise from careful observation of phenomena, or unexpected results, to clarify and/or seek additional information.
- **1.4** Ask questions to clarify and refine a model, an explanation, or an engineering problem.
- **2.3** Develop, revise, and/or use a model based on evidence to illustrate and/or predict the relationships between systems or between components of a system.

These elements will be revisited throughout the unit in various lessons.

This lesson is designed to coherently build on ideas related to the following crosscutting concepts:

- **7.1** Much of science deals with constructing explanations of how things change and how they remain stable.

This element is integral to students' sensemaking in this unit. In this lesson, students should be starting to compare stable and unstable star systems and connect these to related phenomena of systems that seem stable and then suddenly change. Across this unit, students will continually revisit the idea of explaining stability and change within star systems.

Students will not encounter or co-develop meanings for any new scientific vocabulary in this lesson that they will need to keep track of. They will encounter some words that will become important but will have more opportunity to develop meaning for these in future lessons. Do not post any words or ask students to add them to their Personal Glossaries until after your class has developed a shared understanding of their meaning.

Where We Are NOT Going

Students will examine historical accounts of supernova events. However, in this lesson, we will **not** name the event a *supernova*. Students will co-construct the definition of supernova in a later lesson. We will also **not** identify the resulting cloud as a *nebula*.

LEARNING PLAN for LESSON 1

1 · INTRODUCE A NEW PHENOMENON

12 min

MATERIALS: *Guest Star 1054 Location* (can reuse across classes), printed star map, science notebook, sticky dots, chart paper, dry erase markers, world map or globe (optional)

Learn about the guest star of 1054. Present **slide A**. Read the text on the slide aloud: *Historical accounts from around the world describe a "guest star" that appeared in the sky very suddenly in spring of 1054 AD and then disappeared a few months later.* Then ask students to turn and talk about the prompts on the bottom of the slide:

- *Have you spent time looking at stars? What have you seen?*
- *Do stars typically appear or disappear suddenly? How do you know?*
- *Why do you think ancient astronomers were keeping track of the stars?*

Give students a few minutes to discuss then ask students to share. Take a couple of minutes to discuss students' experiences with the night sky and stars. This may include discussing how many stars are visible where you live because of city lights or pollution. ✱ Extend student thinking by asking them to think about important stories, religious and cultural beliefs, family stories, movies, or developing industries that relate to stars. Students may suggest shooting stars or comets right away as examples of stars appearing or disappearing. Validate these ideas and then tell them to keep this in mind as we learn more about these events. Highlight how odd it is for a star to appear for only a few months, given that most of the stars we see in the sky have appeared in the same configurations for all of human history.

ADDITIONAL GUIDANCE

The term *guest star* is a literal translation from ancient Chinese astronomical records used by astronomers throughout the last two millennia. Consider taking a moment to ground students in the history of what the world was like in 1054. Ask them what they imagine may have been happening at that time. The following are some events you might reference from the year 1054. Use a map to orient students to the global locations as you discuss them.

- In Asia, the Seljuk Turks moved west, eventually capturing Baghdad, Armenia, Syria, and Palestine over the next decade. Babylon had been abandoned a few decades earlier. The Song Dynasty controlled most of what is now Eastern China. The Japanese imperial court's political authority entered a period of decline.
- In the Americas, diverse groups of Indigenous peoples covered the continent. Incan and Mayan societies flourished. Anasazi culture was at its height, marked by cities of cliff dwellings in what is now the American Southwest.
- In Africa, the Almoravids retook the trading center of Aoudaghost from the Ghana Empire. The settlement of Mapungubwe began, located in the Limpopo River valley of present-day Zimbabwe.
- In Europe, King Macbeth of Scotland was defeated. This period also marked the final separation between Eastern (Orthodox) and Western (Roman) churches.

Discuss historical records. Present **slide B.** Say, *People all throughout time and all over the Earth have observed the sky and made records of what they saw. Here are some examples of guest star 1058.* Lead students through **slide B,** reading the text aloud, to introduce students to the historical record of this event. Additional information about these images is available in the guidance callout below. Consider orienting students to the areas of the world that each example comes from using a world map or globe. Remind students that there were no telescopes back then, so all we know is that the star faded from the naked-eye view.

✱ ATTENDING TO EQUITY

Access to dark skies for observing the stars is not available to all students. Light pollution and air quality can greatly diminish the visibility of stars in urban areas. Some other reasons students might not be able to see the sky include being outside at night safely or cultural traditions/taboos. Note that observing the sky is NOT integral to the key ideas of this unit. But keep in mind that observing the sky can help students make connections between science content and their lived realities. Work to understand and accept the reasons why students might not be able to observe. Consider discussing the impacts that light pollution can have on both human and nonhuman environments. More information can be found at https://www.fws.gov/project/dark-skies-initiative.

✱ ATTENDING TO EQUITY

Emphasize for students that peoples around the world have developed their own stories and images to describe the patterns of stars and dust they observe in the sky. Ask students about the traditions and stories they have heard in their family or in their community. The free online planetarium software Stellarium allows you to overlay constellation representations from around the world over the stars, including several Indigenous American representations. If you have time, spend a moment showing students some of these constellation mappings and connecting them to stories students might tell about their own cultures.

For more information on Indigenous American astronomy in the past and today, see https://www.legendsofamerica.com/na-astronomyculture/ or https://blog.edvotek.co

ADDITIONAL GUIDANCE

Guidance for **slide B:** On the left is an excerpt from the Lidai mingchen zouyi (歷代名臣奏議), which dates to 1414. The highlighted text reads: 2nd year of the Zhihe reign period of Emperor Renzong of Song [1055]; Attendant Censor Zhao Bian submitted a letter saying: "Your servant considers that, since the 5th month of last year [when] the baleful star appeared, a full year has passed and until now its brilliance has not faded [lit. 'retreated']. This is what Gu Yong meant by 'its rapid movement, the variations in the length of its flaming rays, and the [asterisms] on which it has trespassed successively,' as a censorious anomaly it is greatly to be feared."

In the middle is a second-hand account of a "spectacular star" (athari kawkab) viewed from Constantinople (now Istanbul), in a 1242 book by Ibn Abi Usaibia, a physician from Syria.

On the right is the Japanese text called the Meigetsuki, the diary of Fujiwara no Teika (1162–1241), a poet and courtier.

Lead students through **slide C,** reading the text aloud, to introduce students to the historical record around where this event took place in the sky. Tell students that these records have allowed astronomers to reconstruct exactly where the event was. Pass out the *Guest Star 1054 Location*. These can be reused from class to class.

Map the star together on a laminated map. Before class, you should have found somewhere to post the star map pictured on **slide D**. Let students gather around the laminated star map and orient them to what they see. The words describe IAU (International Astronomical Union) constellations. Point out that constellations are culturally constructed signposts for finding things in the sky and that the IAU has adopted the Greco-Roman system, so we will use it today. ✱ Point to the Milky Way and explain that this band of dust and gas represents the disk of our galaxy across the sky. Take a moment to let students share if they know any constellations (from any culture) or if they have ever seen the Milky Way. Keep in mind that many will not have had that opportunity.

Ask students to find the constellation in which the guest star was located on *Guest Star 1054 Location*. They should say Taurus. Then help them notice where Taurus is on the star map. Show them how the handout indicates nearby constellations as well, making it easier to find Taurus. Orient the handout in the same way as the star map to make the visual connection. Then use a dot sticker to mark the approximate location of the 1054 guest star. Keep in mind that you will need to remove these stickers for the next class.

ALTERNATE ACTIVITY

If you have time, consider using Stellarium, a free online software, to visualize where these stars are in relation to the currently visible night sky in your area. Stellarium is most useful for observing the motions of objects in the night sky and is an important tool in the OpenSciEd Middle School unit (*OpenSciEd Unit 8.4: How are we connected to the patterns we see in the sky and space? (Space Unit)*). At the high school level, the disciplinary core ideas are less focused on patterns in the sky and more focused on stellar lifecycles and cosmology. For this reason, Stellarium was not written into this unit as a sensemaking tool, but it can still be a way to help students make connections between content and the things they can see in the sky.

Begin recording noticings and wonderings in our science notebooks. Present **slide E.** Ask students to make a Notice and Wonder chart in their notebooks and spend a minute jotting down anything that comes up for them right now. Ask students to share one wondering with a partner. Walk around the classroom and listen in. Look for students wondering about if this has ever happened before.

Present **slide F**. Say, *This is not the first time we have seen a system that appears stable changing quickly. For example, when we were learning about earthquakes, we learned about how plate motion can be stable over many years, and then suddenly they slip.* Have students turn and talk with the prompt:

- *What is an example of a system you have seen or learned about that seemed to be stable and then changed very quickly?*
- *What do you think might have caused the sudden change in that system?*

m/2023/10/24/four-native-american-scientists-making-waves-in-todays-scientific-landscape/.

✱ ATTENDING TO EQUITY

Universal Design for Learning: This Related Phenomena poster is used to broaden students' thinking to related phenomena and leverage prior science experiences they have inside and outside of school to support the learning that happens in the classroom. Connecting the stellar anchoring phenomena to students' experience with stable and unstable systems helps the phenomenon become more personally meaningful to each student, supporting their *engagement* with it.

As students talk, sketch a T-chart on a piece of chart paper titled "Related Phenomena." Label the left column "Example of sudden change" and the right column "Causes." Invite students to share. Students may talk about phenomena from previous units, such as earthquakes or a power outage. They might also talk about a building collapse, a plant blooming, or a spontaneous combustion event. Accept all ideas. Record student ideas on the T-chart, pushing students to consider what may cause the sudden changes. ✱ Highlight ideas about forces acting on the system, energy transfer, or changes in matter.

Say, *It seems using our ideas about forces, matter, and energy can be productive to explain stability and change in these systems. Let's see if they can help us understand what is going on with the guest star phenomenon.*

2 · READ ABOUT OTHER GUEST STARS

15 min

MATERIALS: *Historical Guest Stars*, science notebook, M-E-F Triangle poster from previous units

In groups, read about historical observations of another guest star. Say, *This was not the only time this happened. I've got a list of these events with direct observations from witnesses.* Present **slide G**. Go over the task with students. They will read one short description of a guest star event. Refer students to the M-E-F triangle to help them discuss through the lenses of energy-matter-forces and underline the evidence they see. They should use the constellation map to record their event on the class star map. And they should keep track of noticings and wonderings.

Distribute *Historical Guest Stars*. Break the class into groups and assign each group one guest star to read about. ✱

ADDITIONAL GUIDANCE

The readings are written to provide differentiation for students at different reading levels.

Guest Star Reading #1 is written at a 6th grade reading level.
Guest Star Reading #2 is written at a 6th grade reading level.
Guest Star Reading #3 is written at a 7th grade reading level.
Guest Star Reading #4 is written at an 8th grade reading level.

The readings are all short and straightforward, but they require students to parse English translations from several languages, including Old Chinese, Italian, Egyptian (Coptic), and Persian (Farsi). This can be difficult for all students. If students stumble on these translations, ask them to start by picking out words that they recognize and underlining words that they do not. Have them work with a partner to see if they recognized any of the words their partner did not and vice versa. Then ask them if they can make sense of what the translated text means with the words they and their partner knew. It is not important that students understand every word. Rather, support students in drawing out important characteristics of guest stars from the descriptions; for example guest stars are bright, guest stars all appear suddenly, guest stars may have multiple colors, and guest stars eventually fade away.

ADDITIONAL GUIDANCE

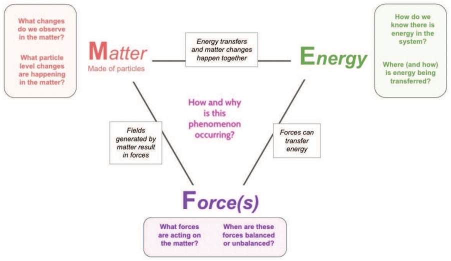
Students may wonder about telescopes. All of these events were visible to the naked eye. The telescope as we know it was invented in 1608, four years after Kepler observed the guest star 1604 (see Reading #4). Make sure questions about this end up on the DQB and/or ideas for future investigations or data we need.

✱ ATTENDING TO EQUITY

The readings include English translations from several languages, including Old Chinese, Italian, Egyptian (Coptic), and Persian (Farsi). If any students in your class can read or speak one of these languages and feel comfortable volunteering this information, ask them to bring the language alive for the class. Make it clear that this knowledge is valuable in science class. Celebrating students' diverse linguistic practices in the classroom is a way to make pedagogy help sustain students' home cultures.

ALTERNATE ACTIVITY

If you are teaching these units out of order, and have not yet developed the Matter-Energy-Forces triangle, you will need to spend some time establishing these ideas. Please see Lesson 3 of *OpenSciEd Unit P.2: How forces in Earth's interior determine what will happen to its surface? (Earth's Interior Unit)* for instructions on how to co-develop this conceptual tool. An example of an M-E-F poster is at right.



3 · DISCUSS IN JIGSAW GROUPS

10 min

MATERIALS: science notebook, chart paper, chart paper markers

Look for evidence in new jigsaw groups that matter is changing, energy is transferring, or that forces are unbalanced. Remind students that stars are really far away, making it hard to collect evidence about matter change, energy transfer, or unbalanced forces. Explain that it may take some work to piece together some of the evidence for what is going on physically from the historical record.

Present **slide H**. Split students into new jigsaw groups so that we have evidence from across events. In these new groups, make sure there is at least one person who has read about each guest star. Ask one group member to facilitate the conversation, making sure that the group talks about each corner of the M-E-F triangle. Ask another group member to monitor participation and make sure that each group member gets a chance to talk about their guest star event.

Students should notice that in all of these examples, the star appeared (or got brighter), changed brightness and color, and then disappeared somewhat quickly. They may also notice that each event was seen in multiple places and appeared to come out of nowhere.

Make a public record of the evidence for each corner of the triangle. As students work, create a poster titled "M-E-F Evidence" and split it into three stacked boxes. After 5-6 minutes of small-group conversation, hold an Initial Ideas Discussion to elicit ideas and make a public record of the evidence that students share, first of matter, then of energy, then of forces in each box. Make sure to label each box as either "M," "E," or "F."

KEY IDEAS	At this point, do not expect students to come up with a lot of ideas about forces, and remember that it is okay for their ideas about matter and energy to be simple, as they do not yet have what they need to explain the phenomenon. However, they should make 2-3 of the following connections to M-E-F using ideas from previous grade bands and units: • Light indicates energy transfer (elementary standards, middle school standards. *OpenSciEd Unit P.1: How can we design more reliable systems to meet our communities' energy needs? (Electricity Unit)*) • Energy transfer is associated with matter changes. (OpenSciEd Chemistry, *OpenSciEd Unit P.2: How forces in Earth's interior determine what will happen to its surface? (Earth's Interior Unit)*) • Energy transfer is associated with unbalanced forces, so even if we do not see evidence of forces, they are implied. (*OpenSciEd Unit P.2: How forces in Earth's interior determine what will happen to its surface? (Earth's Interior Unit)*, *OpenSciEd Unit P.3: What can we do to make driving safer for everyone? (Vehicle Collisions Unit)*) • Color change may indicate matter changes. (OpenSciEd Chemistry) • Color change may also indicate energy transfer because different colors are associated with different energies of electromagnetic radiation. (*OpenSciEd Unit P.5: How do we use radiation in our lives and is it safe for humans? (Microwave Unit)*)

4 · KEEP TRACK OF QUESTIONS

4 min

MATERIALS: science notebook

Take a moment to develop questions individually. Present **slide I**. Ask students to record in their notebooks some questions that have come up so far and be ready to share them with the class. Ask students to share some of their questions if there is time. Otherwise, they can refer back to them next time when we develop a DQB. Look for questions like:

- What is a guest star?
- Where did the guest star come from?
- Where do the guest stars go?
- Are they all the same phenomenon?
- Why are stars stable, while guest stars appear and then disappear?
- Why do guest stars show different colors?
- What was the last guest star humans saw?

5 · NAVIGATE

4 min

MATERIALS: *Stars Home Learning*

Introduce home learning. Present **slide J** and distribute *Stars Home Learning* to each student. Read the text on the top of the slide. *As we saw in the historical record, people from across cultures have made rigorous observations and told valuable stories that are still helping us understand stars.*

Say, *The stars are uniquely visible across the entire planet. People around the world continue to observe and study stars to develop understanding and meaning.* Then introduce the questions on the handout that students should discuss with a family or community member:

- *What experiences, connections, or stories do you have related to stars?*
- *Have you seen stars staying the same over many years? Have you seen stars change?*

Explain to students that experiences, connections, or stories could range from a positive memory or experience to a cultural tradition or event. Suggest that they can draw on their own experiences in addition to those of a family member or another trusted adult.

End of day 1

6 · NAVIGATE

4 min

MATERIALS: None

Review home learning. Present **slide K** and ask students to take out their *Stars Home Learning*. Read the prompts on the slide:

- *What did we learn from talking to others about stars?*
- *What experiences, connections, or stories do you have related to stars?*
- *Have you seen stars staying the same over many years? Have you seen stars change?*

Have students share their findings from their home learning. Affirm students' experiences and highlight ideas about the stars staying the same or changing. Look for a general consensus that the pattern of stars in the night sky stays mostly the same. It is okay if students don't have personal or cultural connections to share.

Consider what tools exist for observing the night sky. Say, *Many of you shared stories about looking at stars with your eyes or someone else looking at the stars with their eyes. Scientists often use tools to observe things more clearly.* Present **slide L**. ✱ Read the prompt on the slide: *What kind of tools could help us collect empirical data about guest stars?* Then have students turn and talk about the prompt.

After a minute or so, have students share. Look for students to suggest things like telescopes ✱ and cameras. Take a moment to discuss that a telescope is a device that uses lenses or mirrors to make distant objects look closer.

ALTERNATE ACTIVITY

If students are especially interested or need more background on how basic telescopes work, here are some resources you can provide or cover as a class.

- An overview of refracting and reflecting telescopes: https://spaceplace.nasa.gov/telescopes/en/
- Information on why they put telescopes in space and Hubble space telescope: https://science.nasa.gov/mission/hubble/overview/why-have-a-telescope-in-space/
- Information on the James Webb space telescope: https://science.nasa.gov/mission/webb/about-overview/

The specifics of how telescopes work is beyond the scope of this unit and does not coherently build toward answering questions about guest stars. Covering how telescopes work in class will take additional time and preparation but also offers an opportunity to integrate optics content and engineering standards.

✱ SUPPORTING STUDENTS IN DEVELOPING AND USING PATTERNS

In high school, students should be engaging with the idea that: "Empirical evidence is needed to identify patterns." While *patterns* is not a focal crosscutting concept developed in this lesson, it will be important for them to understand what it means for evidence to be empirical as they engage with these ideas in Lessons 2 and 6. Take a moment to explain that "empirical" means the data came from observations or experience.

ADDITIONAL GUIDANCE	**Attending to equity:** Telescopes are a contemporary example of how long-standing traditions of decision-making in dominant science can conflict with Indigenous traditions and ways of life. The summit of Maunakea in Hawai'i is an important, sacred place for Native Hawaiians, for whom it is the connection point between land and heavens, and is considered an ancestor of Hawaiian lands and people. The mountain is home to many cultural and historical sites, including burial sites, that are important to Native Hawaiians. Because of the altitude, isolation, location, and weather patterns, the summit of Maunakea is also an ideal place to observe the sky with telescopes, and there are more than a dozen research telescopes located on the site. Now U.S. astronomers want to build a new telescope there called the 30-meter telescope that would be the second-largest telescope in the world. Native Hawaiians are calling for more respectful management of the land and healing of past mismanagement. This includes the decommissioning of some of the current telescopes but still leaves space for the construction of the new telescope, with consideration of cultural priorities. The state of Hawai'i has made an effort to balance both priorities of astronomy and preserving cultural and natural resources of Maunakea. In 2022, the Mauna Kea Stewardship and Oversight Authority (which uses the American spelling of the mountain) was established to help negotiate the management of the land of Maunakea in a way that includes experts from multiple fields, including astronomy, land resource management, Native Hawaiian cultural traditions, and education, some of whom are Native Hawaiians. However, there are still concerns about the specific language of the legislation establishing this group and its priorities. There are also conflicts over the construction of telescopes on Haleakalā in Maui. For more information on the significance of Maunakea for Native Hawaiians, visit https://hilo.hawaii.edu/maunakea/culture/. For more information on efforts to protect the cultural and natural resources of Maunakea, visit https://www.oha.org/aina/mauna-kea/. For more information about the Maunakea observatories, visit https://www.maunakeaobservatories.org/.
ALTERNATE ACTIVITY	If students are interested in observing the night sky and/or using a telescope, help them find a local astronomy club and attend a star party! You can find a club near you at https://nightsky.jpl.nasa.gov/club-map.cfm.

7 · 1987 GUEST STAR DEEP DIVE

5 min

MATERIALS: science notebook

Describe 1987 guest star event in detail as part of a "mini-lecture." Say, *Telescopes are an important tool for observing stars, but they were only invented in 1608. This was a long time ago, but only one guest star has appeared since then. I am going to present to you some information that was collected about the 1987 guest star.*

When you learn about science by taking classes later on or watch TV documentaries about science, it can be really helpful to write down the information that you think is useful. ✱ *I would like you all to turn to a new page in your notebooks and take notes on what you hear that might be useful.* ✱

Use the following script as a loose suggestion of what you might say as you move through **slides M-O**:

Present **slide M.** *Before dawn on February 24, a Canadian astronomer named Ian Shelton was working at an observatory in Chile. He had just begun working on a survey of the Large Magellanic Cloud, a small galaxy that is one of the Milky Way's nearest neighbors in space. He pulled a photographic plate from the developer. Where he expected to see only faint stars, he saw a large bright spot. He was worried that his photograph was flawed. Shelton went outside to look up at the Large Magellanic Cloud in the night sky. It was not a mistake. There was a new bright star there!*

Unlike all previous guest stars visible with only the human eye, the guest star Shelton saw occurred after the invention of the camera; thus we have photographs of the event, pictured here. The bright star near the center is the guest star.

✱ SUPPORTING STUDENTS IN ENGAGING IN OBTAINING, EVALUATING, AND COMMUNICATING INFORMATION

Learning to take notes is an important tool for students when obtaining information from a video, a lecture, or a reading. Encourage students to apply this skill throughout the unit as they obtain information from various internet sources across modalities.

✱ ATTENDING TO EQUITY

Present **slide N.** *Another unique thing about the guest star of 1987 is that it was observed after we had mapped that area of the sky fairly well. So astronomers knew what had been there before. When they looked back at records of that part of the sky, they saw that there had been a star there: Sanduleak. Sanduleak was EXACTLY where the guest star that Shelton observed had appeared. Sanduleak was a big star, estimated to be about 20 times the mass of the Sun. But it was so far away that it was very faint and could not be seen without a telescope.*

Present **slide O.** *When the guest star faded, Sanduleak had disappeared. In its place was a ring, visible only with a telescope, that appeared to change over the next decade, a remnant of what had happened.*

Notice and wonder about the remnant of guest star 1987. Give students a moment to notice and wonder about these photos and add to their Notice and Wonder charts in their science notebooks.

Add guest star 1987 to the map. Present **slide P.** Quickly add guest star 1987 to the star map based on the placement on the slide (between Mensa and Dorado, in the Large Magellanic Cloud).

Supporting emergent multilingual learners: This "mini-lecture" is designed to support students as they transition out of high school science. It provides a lot of information in multiple modalities all at once, which can be overwhelming. To help your students develop tools to be successful in lecture, consider first giving students time to read the slide before you speak. You can print out **slides M-O** for them to annotate and add to their notebooks so that they do not feel pressured to record the details on the screen. Pause at the end of each slide, ask a student to summarize what they added to their notes for that slide before moving on, and give other students a chance to add to their notes as well.

8 · INDIVIDUAL MODELING

12 min

MATERIALS: science notebook

Develop models to explain why the stars we see at night appear not to change, while historical accounts of guest stars describe them changing dramatically. Present **slide Q**. Say, *Much of science deals with constructing explanations of how things change and how they remain stable. Let's see if we can use our current ideas to explain stars that appear to be stable and short-lived guest stars.*

Ask students to make two models in their notebooks and be ready to share.

- One model should explain: *Why do the stars we see every night appear stable over time?*
- The second should explain: *How are guest stars different from these stars, and why do they change so dramatically?*

Remind them that they can use any combination of pictures, symbols, and words and encourage them to use any language that feels useful to them. ✱ Note that the guest star model may consist of multiple parts, such as before, during, and after the guest star is visible.

Share models with a partner through the lens of our M-E-F noticings and then revise models if necessary. After five minutes, present **slide R.** Ask students to pair up. In pairs, they should compare models and discuss the prompts on the slide:

- *What elements did you include in each system?*
- *What differences in matter changes, energy transfer, or forces acting in parts of the system help explain why a start could change?*

Give students a few minutes to discuss and then give students time to individually revise their models.

✱ ATTENDING TO EQUITY

Supporting emergent multilingual learners: Allowing students to use multiple languages allows them to use their full repertoires to make sense of phenomena. The main purpose of the initial modeling is to organize ideas that can then be collected into the consensus model. This means that it is not imperative that everyone can understand each individual's model without facilitation. If you are reviewing a model in which a student used another language and you need to know what they mean, use it as a learning experience and ask them to explain their sensemaking.

ASSESSMENT OPPORTUNITY	**What look/listen for in the moment:** Look for students to: • use words, pictures, and or symbols to represent a stable star and the guest star in two separate models. (SEP: 2.3; DCI: ESS1.A.1) • indicate some mechanism (e.g., energy transfer, matter changes, or unbalanced forces) for why the guest star will change, while the typical star remains stable. It is not important that this mechanism be accurate. (CCC: 7.1; DCI: ESS1.A.1) • use features from historical accounts of guest stars in their model of stars that change.(SEP: 2.3; CCC: 7.1; DCI:ESS1.A.1) **What to do:** • If students are struggling with how to make a distinction between the two models (or if students feel that they already know what is happening), use the M-E-F triangle to prompt them to focus on specific differences in the makeup of the stars the way energy is transferring or even the forces they think may be at work. • If students are still struggling, invite them to begin recording questions they have that are making it hard to model. They can bring these to the Scientists Circle even if they don't have a model yet. **Building Toward 1.A** Develop a model (or set of models) to explain why the stars we see at night appear stable over time, while historical accounts of guest stars describe them changing dramatically. (SEP: 2.3; CCC: 7.1; DCI: ESS1.A.1)

9 · DEVELOP INITIAL CONSENSUS MODEL

10 min

MATERIALS: science notebook, chart paper, chart paper markers

Prepare to create two class consensus models. Gather students in a Scientists Circle around the piece of chart paper titled Initial Consensus Model. Display **slide S.** On a sheet of chart paper, have students represent: one of a stable star system and one of a changing guest star system. Have students lead themselves through constructing the two models as a class, using the prompts on the slide as a starting point:

- *Where do we all seem to agree?*
- *Where do we have shared areas of uncertainty?*
- *Label possible energy transfer, matter changes, and force interactions.*

ADDITIONAL GUIDANCE	As this is the last unit of the course, students should be very familiar with the process of consensus modeling at this point. Ask them to lead themselves through the process with less guidance from you. Have volunteers record the model on the poster for the class and remove yourself from the center of the discussion.

Model the typical star. If students need a starting point, ask, *What was one component both you and your partner included in your model of a stable star system?* As students are modeling a stable star system, look for students to represent:

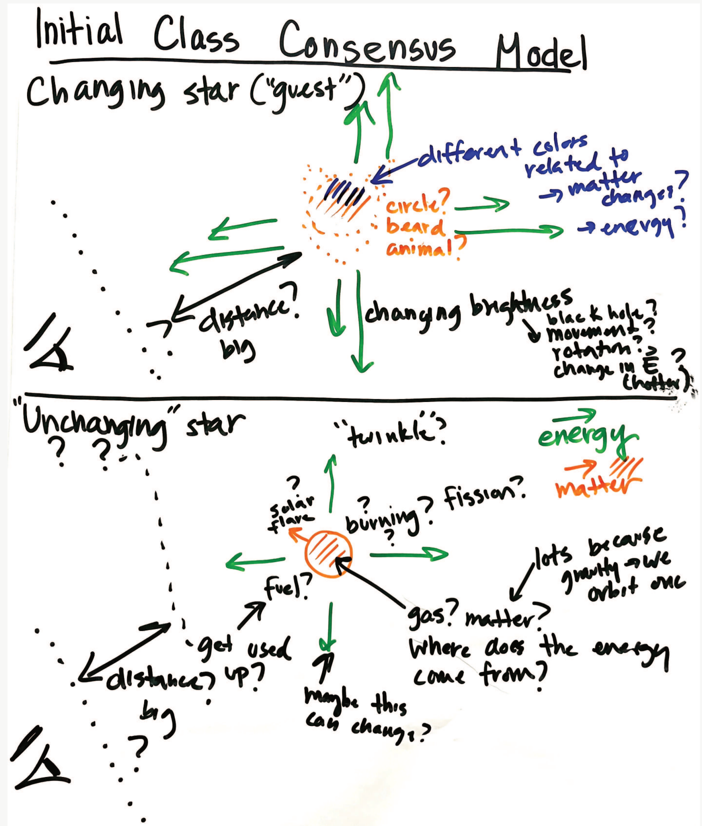
- A round object
- Light, heat, or energy leaving the star
- Some kind of energy source within the star
- Indication of distance or size
- Burning or fire
- Ideas about what the matter is in the star or if there is even matter in a star
- Some students may include hydrogen or helium or nuclear fusion/fission
- Stays the same/is stable over time

Model the guest star. As students are modeling the changing guest star, look for students to represent:

- Changes in energy, brightness

- Changes in color
- Chemical or elementary changes in the matter of the star
- Shapes (bearded, horned)
- Visible for only a short amount of time

Draw out ideas specifically about M-E-F interactions. If students don't label possible energy transfer, matter changes, and force interactions in their model, point to the last prompt on the slide and ask them to add these to the model. Encourage them to use different colors and/or labels with a key to indicate where in our models we are representing possible energy transfer, matter changes, and/or force interactions.



ADDITIONAL GUIDANCE	If students are struggling with labeling possible energy transfer, matter changes, and/or force interactions, point to the M-E-F triangle poster developed over the previous units and use the questions on the triangle to scaffold student thinking.

Your model may look something like the image at right.

Consider scale. Highlight student ideas about stability and change on the consensus model. Say, *When figuring out ideas related to Earth Science and forces in Earth's Interior Unit, we used a scale chart to organize our ideas about scale and stability and change. Let's see if these ideas can help us make sense of guest stars too.* Present **slide T.** Read the top of the slide, which states "All Systems Change. Stability is dependent on scale." Remind students that this was at the middle of our scale chart in *Earth's Interior Unit*. Ask students what they think it means for stability to depend on scale in this case. Look for ideas about how even though the stars seem stable over one person's lifetime, if we look at the historical record, they change.

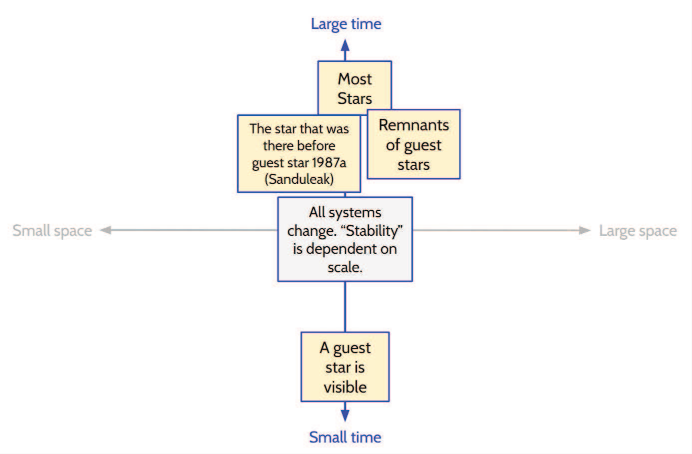
Pose the question on the slide: *How do the objects we have been investigating in the sky change over different scales?* Look for students to say time. Then suggest drawing a time scale chart to keep track of the ideas about stability and change over time.

On a new piece of chart paper, draw a vertical axis as a time scale chart with “large time” at the top and “small time” at the bottom. Remind students about the scale chart we used in *Earth's Interior Unit*. Ask students what phenomena they think should be added to the chart. Write these on sticky notes and place them on the time scale according to student ideas. Exact placement is not important.
Possible sticky notes include:

- A guest star is visible (in small time).
- Most stars/stable stars/regular stars are visible.
- Remnants of guest stars are visible.
- The star that was there before guest star 1987a (Sanduleak) existed.

Most stars, the remnants, and the star that was there before the guest star should all be somewhere in “large time,” with most stars being the largest time since they have stayed the same throughout the time of all other things combined. If students also bring up spatial scale differences, it is fine to add a horizontal space scale. For most classes, this will be added in Lesson 3.

Once the phenomena/objects have been added to the scale chart, remind students that we used the scale chart to think about stability over time. Write “All systems change. ‘Stability’ is dependent on scale.” to match what was on the scale chart in *Earth's Interior Unit*. An example of what the scale chart might look like is shown.

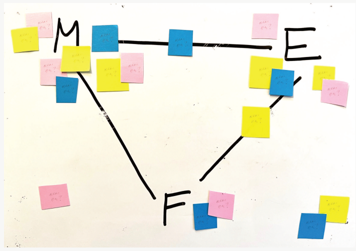


10 · BUILD THE DQB

8 min

MATERIALS: science notebook, paper or sticky notes for DQB questions, tape

Develop questions for the DQB. Ask students to develop questions for the DQB on their own using **slide U.**



Build the DQB. Present **slide V**. Tell students, *We have been organizing our ideas in terms of matter, energy, and forces. Let's try organizing our DQB that way to make visible what kinds of questions we have about this phenomenon and help us figure out where we want to go first.*

Draw an M-E–F triangle as the backdrop of the DQB. You do not need to add any details beyond the letters M, E, and F.

Ask for a volunteer to get the process of building the DQB started. Ask students to take responsibility for facilitating the process. You can assign one or two students to take on the role of choosing new volunteers and keep up the momentum if the process slows down.

ASSESSMENT OPPORTUNITY

What look/listen for in the moment: Look for students to ask questions (SEP: 1.1):

- about the early guest star of 1054 and those they read historical accounts of in the activity. (SEP: 1.1; DCI:ESS1.A.2)
- about the causes of guest stars to suddenly appear and disappear. (CCC: 7.1; DCI: ESS1.A.2)
- related to uncertainties in their models of stable stars and changing guest stars. (SEP: 1.4; CCC: 7.1; DCI: ESS1.A.2)
- that seek additional information about what causes guest stars to change brightness, shape, and/or color. (SEP: 1.1; CCC: 7.1; DCI: ESS1.A.2)

What to do:

- If students are struggling with asking questions, suggest they look at their Notice and Wonder charts and think of what they cannot explain related to how the guest star is different from a stable star.
- If students are still struggling, ask them if they had difficulty modeling these two stars and to think of questions they might ask that answering would make their modeling easier.
- If you have students put their initials on the questions they post, you can review individual questions after class to get a greater sense of where your students are for asking questions in this lesson.

Building Toward 1.B: Ask questions that arise from historical observations of dramatic changes in the brightness, shape, and color of stars to clarify our models and seek additional information. (SEP: 1.1, 1.4; CCC: 7.1; DCI: ESS1.A.2)

11 · NAVIGATE: NEXT STEPS

6 min

MATERIALS: chart paper, chart paper markers

Briefly brainstorm ideas for investigations and data we need. Present **slide W**. Read the prompt on the slide and elicit student ideas: *What kinds of investigations could we carry out and what additional sources of data might we need to figure out the answers to our questions?*

Keep track of student ideas on a new piece of chart paper. ✱

Navigate to where we are going next. Say, *Which of our questions and investigation ideas are related to more closely observing the location in the sky specified by astronomers who witnessed these events?* Follow-up by saying, let's plan to start our investigations next class with looking at some of the data collected by telescopes that have taken photographs of those places.

✱ SUPPORTING STUDENTS IN DEVELOPING AND USING SCALE, PROPORTION, AND QUANTITY

This is a good time to highlight the fact that stars are too large and too far for us to investigate directly and that many of the phenomena we are wondering about happen over very long time scales. Even though we can't make direct observations on our own, we can use data from observations made by astronomers using telescopes both recently and in the past.

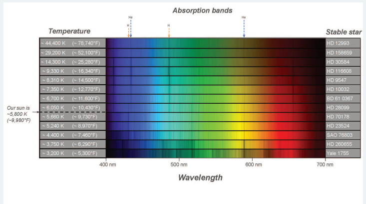
LESSON 2: How does the matter in guest stars compare to stable stars?

PREVIOUS LESSON *We discovered that guest stars are stars that seem to appear suddenly and then disappear in a relatively short time. These events happen within our galaxy and have occurred recently (1987). We wondered what we would see if we looked at the night sky with a telescope and pointed it in the area where these events occurred.*

THIS LESSON

INVESTIGATION

1 day



Adapted from: Dintsios, N., Artemi, S., & Polatoglou, H. (2018).

We compare photos of the parts of the sky where some of these guest star events were observed and notice remnants of what looks like gas or dust. We analyze spectra to determine the composition of the matter that these remnants are made of and its temperature. We compare these to the spectra of stable stars and add to our Progress Trackers. We ask new questions and add them to our Driving Question Board.

NEXT LESSON *We will consider how studying energy and matter in stable stars could help us answer our questions. We will be introduced to two new tools, the Planning for Obtaining Information Tool and the Obtaining Information Tool, and we will use them to research answers to our questions. We will come to consensus and record our ideas in our Progress Trackers and Personal Glossaries. We will revisit the DQB.*

BUILDING TOWARD NGSS

HS-ESS1-1, HS-ESS1-2, HS-ESS1-3, HS-PS1-8

WHAT STUDENTS WILL DO

2.A Integrate information from multiple spectra representations to describe differences in the composition and temperature scale of a stable star versus guest stars. (SEP: 8.2; CCC: 3.1; DCI: ESS1.A.2)

2.B Ask questions that arise from the spectra of a guest star to seek additional information about how and why some stars appear to remain stable for so long and others change so quickly. (SEP: 1.1; CCC: 7.1; DCI: ESS1.A.2)

WHAT STUDENTS WILL FIGURE OUT

- Stable stars are made of mostly hydrogen and helium, and their temperatures vary across a certain range.
- Hydrogen and helium are the two lowest-mass elements.
- Temperatures of stable stars range from thousands to ten thousands °C or °F. Temperatures of guest star remnants are millions °C or °F.
- Guest star remnants contain elements other than hydrogen and helium and in some cases no hydrogen and helium.

Lesson 2 • Learning Plan Snapshot

Part	Duration		Summary	Slide	Materials
1	3 min		**NAVIGATE** Make predictions and consider how telescopes can help provide us some of the data we would need to support/refute our predictions.	A	Ideas for Investigations and Data We Need posters from Lesson 1, printouts of slides B-G (optional)
2	10 min		**ANALYZE IMAGES OF GUEST STAR REMNANTS AND THE SUN** Examine images of guest star remnants and compare those to the Sun. Consider what information we need to determine the composition of the remnants..	B-K	*Progress Tracker*, chart paper, chart paper markers, color printouts of slides C-H (optional)
3	Optional 12 min		**OPTIONAL: REVIEW HOW SPECTROSCOPY WORKS** This section is provided if you determine you need to review how spectrography works. Skip this section if students recall their work in a prior chemistry unit, using absorption spectra to identify atmospheric composition.	L-S	
4	16 min		**ANALYZE DATA TO IDENTIFY THE COMPOSITION AND TEMPERATURE OF STABLE STARS** Use spectroscopy to identify the similarity in the elemental composition and the temperature range of stable stars.	T-X	*Periodic Table*, dry erase markers
5	8 min		**MAKE PREDICTIONS AND ANALYZE GUEST STAR REMNANTS** Have students use spectroscopy to identify the differences in the elemental composition and the temperature range of remnants compared to stable stars.	Z-BB	*GuestStar Spectra*, *Periodic Table*, *Star Spectra*
6	8 min		**ASK QUESTIONS** Have students integrate additional information on guest star spectra with the evidence they have analyzed so far.	CC-DD	*Progress Tracker*, sticky notes, permanent marker, *Periodic Table*, *Star Spectra*, *GuestStar Spectra*

End of day 1

Lesson 2 • Materials List

	per student	per group	per class
Lesson materials	• science notebook • *Progress Tracker* • *GuestStar Spectra* • notebook paper • sticky notes • permanent marker	• *Periodic Table* • *Star Spectra* • *GuestStar Spectra*	• Ideas for Investigations and Data We Need posters from Lesson 1 • printouts of slides B-G (optional) • chart paper • chart paper markers • color printouts of slides C-H (optional) • dry erase markers

Materials preparation (45 minutes)

Review teacher guide, slides, and teacher references or keys (if applicable).

Make copies of handouts and ensure sufficient copies of student references, readings, and procedures are available.

Three-hole-punch all handouts so they can be added to students' notebooks.
Compare *GuestStar Spectra* to *GuestStar Spectra v2*. Note that *GuestStar Spectra v2* has the annotations related to missing hydrogen and helium removed. The removal of these annotations increases the opportunity for student sensemaking and prepares students more for the type of independent research and spectral analysis they will need to be doing in future lessons. If you choose to use *GuestStar Spectra v2* instead of *GuestStar Spectra*, you may want to also allocate an additional 3 minutes for the work on **slide Y**.

Make copies of the following references to distribute and collect to reuse across your classes for every pair of students in your largest classes.

- A black and white copy of *Periodic Table*.
- A color copy of *Star Spectra*.
- A color copy of *GuestStar Spectra* (or *GuestStar Spectra v2* if you chose to use this less scaffolded verizon).

Make a copy of *Progress Tracker* for each of your students. The structure of this Progress Tracker is one that students were first introduced to in this prior unit: *OpenSciEd Unit P.4: Meteors, Orbits, and Gravity (Meteors Unit)*.

Talk with your chemistry teachers and determine if students have previously analyzed absorption spectra. If they have, like in *OpenSciEd Unit C.3: How could we find and use the resources we need to live beyond Earth? (Space Survival Unit)*, then it is assumed you will skip **slides L-S** in this lesson. Review **slides L-S**, though, either way to determine if your students would benefit from this optional section to review how spectrography works. If you do use these slides, add 12 minutes to the lesson plan.

If students would benefit from looking at the photos of the remnants up close, print **slide H** in color or **slides B-G** to hand out at the start of class.

Lesson 2 • Where We Are Going and NOT Going

Where We Are Going

This lesson is designed to build ideas around the following disciplinary core idea element:

- **ESS1.A.2** The study of stars' light spectra and brightness is used to identify compositional elements of stars~~, their movements, and their distances from Earth.~~ (HS-ESS1- 2),(HS-ESS1-3)

In this lesson, students develop the idea that spectra tell us what stars are made of. In Lesson 6, students will learn about redshift, which connects to motion and distance.

The ideas developed in this lesson provide the foundation for ESS1.A.4, which will be covered in Lesson 6.
Students have developed a model of the entire electromagnetic spectrum in their prior unit of study: *OpenSciEd Unit P.5: How do we use radiation in our lives and is it safe for humans? (Microwave Unit)*.

Students who have taken chemistry, particularly if they have experienced *OpenSciEd Unit C.3: How could we find and use the resources we need to live beyond Earth? (Space Survival Unit)*, will be relying on their understanding of the following disciplinary core idea element in this lesson to make sense of spectra:

- **PS4.B.4:** Atoms of each element emit and absorb characteristic frequencies of light. These characteristics allow identification of the presence of an element, even in microscopic quantities. (secondary to HS-ESS1- 2)

These ideas and how spectrograph works were developed in this prior unit of study in the OpenSciEd Chemistry course: *OpenSciEd Unit C.3: How could we find and use the resources we need to live beyond Earth? (Space Survival Unit)*. If students have not taken chemistry, this lesson offers an alternate activity (optional **slides L-S**) that supports students in filling the gaps they need to engage in the sensemaking that follows. This adds about 12 minutes to the lesson.

This lesson is designed to coherently build on ideas related to the following science and engineering practice:

- **1.1** Ask questions that arise from careful observation of phenomena, or unexpected results, to clarify and/or seek additional information.

Students continue developing questions around the anchoring phenomenon in this lesson. In future lessons, students will extend their engagement in this practice by developing research questions that they will then conduct internet research to answer.

- **8.2** Compare, integrate, and evaluate sources of information presented in different media or formats (e.g., visually, quantitatively) as well as in words in order to address a scientific question or solve a problem.

In this lesson, students integrate across multiple visual representations of stars and guest star remnants. In the next lesson, they integrate across internet resources that include multiple formats and begin to consider evaluating their credibility. In Lesson 4, students will dig deeper into how to evaluate sources.

This lesson is designed to coherently build on ideas related to the following crosscutting concepts:

- **3.1** The significance of a phenomenon is dependent on the scale, proportion, and quantity at which it occurs.

In this lesson, students begin to consider the significance of scale through guest star remnants being 10 times hotter than stable stars. This element will continue to be developed more explicitly across Lessons 3 and 5, where the students will further develop the Scale Chart seeded in Lesson 1.

- **7.1** Much of science deals with constructing explanations of how things change and how they remain stable.

This lesson continues to make explicit the idea of comparing stable stars to changing guest stars. This element will continue to be developed throughout most lessons of this unit.

Because students developed the meaning of *spectroscopy* and *absorption lines* in that previous unit, they are not added to their Personal Glossaries in this lesson. If this is your students' first experience with spectrography, you may want to provide additional time to have students add their own definitions of these words to their Personal Glossaries. **Do not** post any words or ask students to add them to their Personal Glossaries until after the class has developed a shared understanding of their meaning.

Where We Are NOT Going

Although students explore how spectra can be used to make inferences about the composition and temperature of stars, how we can use light to determine the chemical composition of a distant object is covered in more depth in OpenSciEd High School Chemistry.

We are not identifying the other elements in the spectra of the Sun beyond hydrogen and helium. This is intentional, as it will help lead students to wonder if the other elements they see in the guest star remnant spectra are also in stable stars. We are avoiding referring to the mechanism that produced the guest stars or their remnants (supernova) in this lesson, as this is what students will be figuring out in future lessons. The lesson also avoids identifying types of stars.

The absorption graphs in *GuestStar Spectra* and *GuestStar Spectra v2* represent those that are produced from the supernova event (guest star), rather than from the guest star remnants seen in the telescopic false color images. We avoid this distinction in this lesson.

LEARNING PLAN for LESSON 2

1 · NAVIGATE

3 min

MATERIALS: science notebook, Ideas for Investigations and Data We Need posters from Lesson 1, printouts of slides B-G (optional)

Make predictions. Present **slide A**. Use the slide prompts to discuss some of the ideas from the previous lesson and to motivate where to go next:

- *What do you think we would find now in the region where each guest star appeared and then disappeared?*
- *How can telescopes help provide some of the data we need to support/refute our predictions?*

Accept all answers.

Say, *Let's look at some images of guest star remnants and compare those with a stable star, our Sun, compared to our predictions. These images we will see in the next few slides were produced from data collected by telescopes both on Earth and in Earth's orbit.*

2 · ANALYZE IMAGES OF GUEST STAR REMNANTS AND THE SUN

10 min

MATERIALS: *Progress Tracker*, chart paper, chart paper markers, color printouts of slides C-H (optional)

Project images of guest star remnants and the Sun. Present **slides B-F**, showing the images in the sky where remnants of guest stars were recorded. Then display **slide G** to have the class observe two images of the Sun. Show each **slide B-G** individually for several seconds and then stop on the composite image on **slide H.** Create a Notice and Wonder T-chart on a piece of chart paper. Ask students to share some of what they notice and wonder for about 3 minutes. Sample student responses include:

Noticings:

- The remnants look like a cloud of matter.
- The remnants look like vapor or a gas.
- There are lots of multiple colors in images of the remnants.
- The shape of the cloud is close to spherical.
- There are fewer colors in some of the images.
- The Sun is closer to spherical shape than the remnants.

Wondering:

- Is there something in the middle of the remnants / cloud / gas / vapor?
- What matter is in the cloud / gas / vapor?
- Does the cloud / gas / vapor come from something (a star?) that exploded?
- Do these emit or glow with visible light like a star?
- Are these remnants hot like a star?
- Are the remnants made of the same things as stars?
- Why do the remnants / cloud / gas / vapor show up in multiple colors, but the Sun is shown only in one?

Make inferences about stars based on images. Present **slide I**. Ask students to turn and talk with the prompts:
Based on the images of these objects:

- *What inferences can we make about the differences between stable stars and guest stars?*
- *What do they tell us may have happened to the matter that made up the guest star?*

Invite a few volunteers to share their ideas. Accept all ideas. Example responses may include:

- They are made of different stuff.
- Stable stars look brighter, so maybe they are hotter.

- The matter of guest stars breaks down.
- The matter of guest stars is dispersed in space.
- The guest star is a stable star that was destroyed.

Add to Progress Tracker. Present **slide J.** Distribute *Progress Tracker*. Cue students to prepare a Progress Tracker entry to record what they figured so far related to this question for two minutes:
- How does the matter in the remnants of a guest star compare to stable stars?

Then emphasize that they will add more ideas to this entry at the end of the lesson after we dig into some more data.

ADDITIONAL GUIDANCE	The structure of this Progress Tracker is one that students were first introduced to in this prior unit: *OpenSciEd Unit P.4: Meteors, Orbits, and Gravity (Meteors Unit)*.

Identify measurements. Present **slide K**. Elicit 1-2 student ideas with the prompt:
- *What measurements or observations can we make from the light that is captured by our telescopes to understand the composition of stable stars and their guest star remnants?*

Accept all answers.
- If students suggest spectrography, based on their work from a period unit: *OpenSciEd Unit C.3: How could we find and use the resources we need to live beyond Earth? (Space Survival Unit)*, then validate that this technique is one that scientists use to study the matter of space objects. You may now skip the next section of optional slides (**L-S**).
- If students do not suggest spectrography, then say, *Another tool scientists use to study the matter of space objects is using the light that is being detected by the telescopes that were used to produce the images on the previous slides.*

3 · OPTIONAL: REVIEW HOW SPECTROSCOPY WORKS

Optional 12 min

MATERIALS: None

ADDITIONAL GUIDANCE	This section is intended to be a short review of how spectrography works. It is relatively abbreviated, since a more comprehensive introduction to it is developed in this prior unit of study in the Chemistry course sequence: *OpenSciEd Unit C.3: How could we find and use the resources we need to live beyond Earth? (Space Survival Unit)*. Skip this section if students recall having used spectrography in that period to identify the composition of gasses.

Connect to prior experiences. Present **slide L**. Say, *Since we are talking about how we can use the light coming from stars and remnants of guest stars, let's consider some light sources closer to us.*

Give students a moment to think about the slide prompt:
- *How would you describe the color of light produced by all three light sources?*

Invite a couple of volunteers to share. Look for students to say that the light is white or white-ish or tinted a bit (off-white).

Make predictions. Present **slide M.** Have students turn and talk with the prompt:
- *What would we see if we passed some of the light coming from one of these light sources through a prism?*

After a minute, invite them to share. Listen for students to mention that the person will see different colors. It is not important if students do not mention this idea at this point.

Connect to prior experiences. Present **slide N.** Use the slide image to introduce the word *spectrum* as reference to all the colors of light that are produced when white light is separated by different wavelengths. Present **slide O** to introduce the idea that separation of white light into a spectrum of colors can also be seen in some cases where sunlight interacts with other shaped objects made of glass or crystal or ice/water droplets. Point out that camera lenses often produce such an effect when sunlight goes through them at a certain angle, which is something you can see in photos of the Sun shown on the slide.

Make predictions. Present **slide P.** Say, *Let's imagine that we place a cylinder filled with gas that allows some of the light from the bulb to pass through. If the gas inside the cylinder absorbs yellow light, what do you think the spectrum will look like?* Give students a moment to think about this question on their own.

Use a model. Present **slide Q**. Use the images on the slide to help students understand that:
- The dark band we would see in the spectrum corresponds to the color that was absorbed.
- Such a dark band in a spectrum is called an absorption line.
- Every element absorbs a unique set of wavelengths of light.
- Scientists can identify the composition of any gas from the absorption lines in the spectrum it produces.

Make predictions. Present **slide R.** Say, *What would the absorption spectrum for Sample A look like if it contained a mixture of both hydrogen and oxygen?* Give the class a few moments to look at the images.

Compare predictions. Present **slide S.** Say, *Stable stars produce light of all wavelengths. As this light goes through gas around the outside of the star, some wavelengths of the light get absorbed.*

4 · ANALYZE DATA TO IDENTIFY THE COMPOSITION AND TEMPERATURE OF STABLE STARS

16 min

MATERIALS: *Periodic Table*, dry erase markers

Make predictions. Present **slide T.** Read the text on the slide: *Stable stars produce light of all wavelengths. As this light goes through the gas around the outside of the star, some of it gets absorbed, depending on the elements that make up that gas.*
Then ask, *What elements do you think the absorption spectra from the Sun will indicate it is primarily made of?* Give students a few moments to consider their predictions.

Analyze data. Present **slide U.** Ask, *How would this spectrum support the claim that hydrogen is one of elements that make up the Sun?* Give students two minutes to discuss this with a partner. Have students share their ideas with the class. Look for students to say that since the absorption bands for hydrogen appear in the Sun spectrum, hydrogen must be one of the elements that make it up.

Compare spectra representations. Present **slide V.** Read the text on the slide, *Scientists also use graphs like this to represent the intensity of the light across a spectrum.* Then discuss the question on the slide as a class. Look for students to say that the absorption lines are where there are dips in the intensity graph.

ADDITIONAL GUIDANCE	Students also developed these types of graphs for representing intensity of light across a spectrum in this prior unit: *OpenSciEd Unit C.3: How could we find and use the resources we need to live beyond Earth? (Space Survival Unit)*.

Connect to prior experience. Display **slide W.** Read the text at the top of the slide, *Empirical evidence from spectral analysis has helped scientists determine that hydrogen and helium make up over 98% of the matter in our Sun*.

Use a model. Display **slide X.** Distribute *Periodic Table* to every pair of students. Discuss the question on the slide as a class, *How do the atomic masses of helium and hydrogen compare to other elements?* Look for students to say that hydrogen and helium are the lowest-mass elements of the periodic table.

ADDITIONAL GUIDANCE	Astronomers sometimes refer to the elements with lower atomic masses (AMU) on the periodic table as the lightest elements and the ones with higher atomic mass elements on the periodic table as heavier elements.

Analyze spectra of stable stars. Present **slide Y**. Distribute *Star Spectra* to every pair of students. Have students work with partners to explore the question on the slide, *What patterns do you notice in these stable star spectra?* After 4 minutes, invite volunteers to share. Listen for the following ideas:

- The spectra of some stars are brighter around the blue colors but darker around the red colors.
- The spectra of some stars are brighter around the red colors but darker around the blue colors.
- There are similar absorption bands across all starts.
- In the spectrum of some stars, the absorption bands are thicker and/or lower intensity.

Ask students this follow-up question, *What is the range of temperatures that stable stars come in.* Listen for the following idea and write it on the board:

- Stable stars range in temperature is thousands °C (or °F).

Ask students this follow-up question, *If all of these stars all have some absorption bands that are similar, what does that tell us about the elements that make them up?* Listen for the following idea:

- They must have one or more elements common to all of them.

Write this statements on the board:

- Most stable stars, like our own Sun, are composed almost entirely of hydrogen and helium.

5 · MAKE PREDICTIONS AND ANALYZE GUEST STAR REMNANTS

8 min

MATERIALS: *GuestStar Spectra*, notebook paper, *Periodic Table*, *Star Spectra*

Make predictions. Display **slide Z.** Take a poll on how the type of matter that makes up the remnants of guest stars will compare to stable stars. Display **slide AA.** Take a poll on how the temperature of matter will compare.

ALTERNATE ACTIVITY	**Extension Opportunity** *GuestStar Spectra v2* has the annotations related to missing hydrogen and helium removed that are included in *GuestStar Spectra*. The removal of these annotations increases the opportunity for student sensemaking and prepares students more for the type of independent research and spectral analysis they will need to be doing in future lessons. If you choose to use *GuestStar Spectra v2* instead of *GuestStar Spectra v2*, you may want to also allocate an additional 3 minutes for the work on **slide Z**.

ADDITIONAL GUIDANCE	We are referring to guest star remnants as whatever is left over after guest stars go from being visible to no longer visible with the unaided eye from Earth. The exact point in time when a guest star becomes a remnant is not an important distinction.

Compare spectra and add to Progress Tracker. Display **slide BB.** Distribute *GuestStar Spectra*. Have students integrate the additional information on this with prior evidence they analyzed so far on *Progress Tracker* and add to their Progress Trackers.

ASSESSMENT OPPORTUNITY

What to look/listen for: Integrate and compare across multiple spectral representations to figure out (SEP: 8.2; DCI: ESS1.A.2):

- Stable stars are made of mostly hydrogen and helium. (DCI: ESS1.A.2)
- Guest star remnants contain elements other than hydrogen and helium and in some cases no hydrogen or helium. (DCI: ESS1.A.2)
- Guest stars are over ten times hotter than stars. (CCC: 3.1; DCI: ESS1.A.2)

What to do: Use the following prompts to help facilitate student thinking:

- What does *Star Spectra* tell us about the type of matter that makes up stable stars?
- What does the temperature range tell us about the matter that makes up stable vs. guest star remnants? Why is the difference in temperature significant?

Building Toward 2.A Integrate information from multiple spectra representations to describe differences in the composition and temperature scale of a stable star versus guest stars. (SEP: 8.2; CCC: 3.1; DCI: ESS1.A.2)

6 · ASK QUESTIONS

8 min

MATERIALS: *Progress Tracker*, sticky notes, permanent marker, *Periodic Table*, *Star Spectra*, *GuestStar Spectra*

Ask questions. Display **slide CC.** Distribute two sticky notes and a marker to each student. Have students record new questions they now have, one on each sticky note.

Share questions. Display **slide DD.** Meet in a Scientists Circle. Have each student read their question and add it to the DQB. Ask them to consider if their question is more about matter, energy, or forces and to place their question in the appropriate category on the board. As they answer their questions, their answers may be associated with a different category, and they can move their question to the appropriate category later. If a student has a similar question to the one read aloud, they can put similar questions together. New questions that may surface include:

- Could the remnants form a star?
- How are stars formed?
- Are the remnants from a star that blew up?
- Why are the remnants from a guest star so much hotter than stars?
- Is the reason a star is hot the same as the reason the remnants are hot?
- Where does energy come from for all of this?
- Why are there elements in remnants that are different from what is in most stable stars?
- Why are stable stars mostly hydrogen and helium?
- Is the lower AMU of hydrogen and helium related to what makes stars shine?
- Do the spectra of the remnants change over time?
- What elements are guest stars actually made of?
- Why is there no hydrogen or helium found in some guest star remnants?
- Why are elements other than hydrogen found in some guest star remnants?

ADDITIONAL GUIDANCE

If students have already mentioned the term *supernova* and connected it with guest stars, it's okay. We are working to develop a deep understanding of the life cycles of stars and what causes guest stars, which involves deeper understanding than identifying that a supernova is the event we see from Earth as a guest star.

ASSESSMENT OPPORTUNITY	**What to look/listen for**: • Questions that connect to the composition and/or the temperature of the guest star remnants. (SEP: 1.1; DCI: ESS1.A.2) • Questions that connect to whether the spectra of a stable star, guest star, or guest star remnants change over time. (SEP: 1.1; CCC: 7.1 DCI: ESS1.A.2) • Questions about if/how stars and guest stars change and why they change. (SEP: 1.1; CCC: 7.1; DCI: ESS1.A.1) • Questions about what keeps most stars stable for so long. (SEP: 1.1; CCC: 7.1) **What to do:** Encourage students who struggle to ask questions to either: a) consider what they would like to know or understand, first from a matter perspective and the second from an energy perspective, or b) consider what questions they have about longer-term stability and relatively rapid change in these stellar objects. **Building Toward 2.B** Ask questions that arise from the spectra of a guest star to seek additional information about how and why some stars appear to remain stable for so long and others change so quickly. (SEP: 1.1; CCC: 7.1; DCI: ESS1.A.2)

Indicate that we will try and make progress on some of these new questions next lesson. Collect the following to reuse across classes:

- *Periodic Table*
- *Star Spectra*
- *GuestStar Spectra*

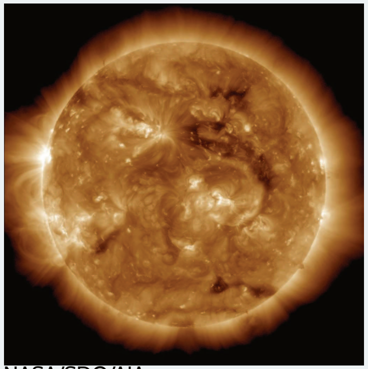
LESSON 3: What is happening with matter and energy in stable stars, like our Sun, and how does this help us understand guest stars?

PREVIOUS LESSON *We compared photos of the parts of the sky where some of these guest star events were observed and noticed remnants of what looked like gas or dust. We analyzed spectra to determine the composition of the matter that these remnants are made of and its temperature. We compared these to the spectra of stable stars and added them to our Progress Trackers. We asked new questions and added them to our Driving Question Board.*

THIS LESSON

INVESTIGATION

2 days



NASA/SDO/AIA

We consider how studying energy and matter in stable stars, including the Sun, could help us answer our questions about guest stars and form research groups. We are introduced to the [material: PB.L3.HO1] and consider the credibility of sources. We use a new tool called the Obtaining Information Tool to keep track of what we find out. We come to consensus around the answers to our research questions and record our ideas in our Progress Trackers and Personal Glossaries. We revisit questions on the DQB.

NEXT LESSON *We will model the macro forces of a star to help us figure out what keeps stars stable. We will develop research questions, and we will be introduced to a new tool for evaluating sources. We will gather information and communicate our findings in a gallery tour. We will come to consensus on what causes stars to remain stable or become unstable and change and record those ideas in our Progress Trackers.*

BUILDING TOWARD NGSS

HS-ESS1-1, HS-ESS1-2, HS-ESS1-3, HS-PS1-8

WHAT STUDENTS WILL DO

3.A Compare and integrate information about nuclear processes in stars and how their scale affects their significance from a list of web sources in order to obtain information to address a question and make progress on our models of why and how stars like the Sun change at the beginning and middle of their lives. (SEP: 8.2; CCC: 3.1, 5.2, 5.5; DCI: ESS1.A.4, PS1.C.1, PS3.D.4, ESS1.A.1)

WHAT STUDENTS WILL FIGURE OUT

- A star is an object that is massive enough to ignite fusion.
- Energy from fusion causes stars to emit electromagnetic energy.
- Fusion results in new elements as multiple nuclei become one.

Lesson 3 • Learning Plan Snapshot

Part	Duration		Summary	Slide	Materials
1	5 min		**NAVIGATE** Motivate the investigation of matter and energy of stars.	A-B	DQB
2	10 min		**INTRODUCE THE PLANNING FOR OBTAINING INFORMATION TOOL** Introduce, distribute, and complete the *Planning for Obtaining Information Tool*.	C-D	*Planning for Obtaining Information Tool*
3	15 min		**CONSIDER CREDIBILITY** Share initial ideas about what makes a source credible. Preview example websites as a class.	E-F	*Planning for Obtaining Information Tool*
4	15 min		**INTRODUCE THE OBTAINING INFORMATION TOOL AND BEGIN THE FIRST RESEARCH CYCLE** Introduce, distribute, and complete the *Pre-Filled Obtaining Information Tool*.	G-H	*Pre-Filled Obtaining Information Tool*
					End of day 1
5	10 min		**CONTINUE FIRST RESEARCH CYCLE** Continue to use the *Obtaining Information Tool* to research student questions about stars and the remnants of guest stars.	H	*Pre-Filled Obtaining Information Tool*
6	15 min		**BUILD CONSENSUS IN A SCIENTISTS CIRCLE** Come to consensus around research questions.	I-J	*Pre-Filled Obtaining Information Tool*, chart paper, chart paper markers, Scale Chart poster from Lesson 1
7	10 min		**MODELING OUR SUN, A STABLE STAR** Individually model the matter and energy within stars and then develop a consensus model.	K-L	copy paper, chart paper, chart paper markers
8	5 min		**KEEP TRACK OF OUR IDEAS** Keep track of our ideas in our Progress Trackers and Personal Glossaries.	M	*Progress Tracker*
9	5 min		**NAVIGATE** Revisit earlier questions and add questions to the DQB.	N	3x3 sticky notes, permanent marker, DQB
					End of day 2

Lesson 3 • Materials List

	per student	per group	per class
Lesson materials	• *Pre-Filled Obtaining Information Tool* • copy paper • science notebook • *Progress Tracker* • 3x3 sticky notes • permanent marker	• *Planning for Obtaining Information Tool*	• DQB • chart paper • chart paper markers • Scale Chart poster from Lesson 1

Materials preparation (20 minutes)

Review teacher guide, slides, and teacher references or keys (if applicable).

Make copies of handouts and ensure sufficient copies of student references, readings, and procedures are available.

Three-hole-punch all handouts so they can be added to students' notebooks.

Before Day 1
Prepare two example websites ahead of time for students to assess credibility. Do this by searching for one of the research questions. Go through and select sources that you think would be more beneficial to the conversation. This may include using one of the sources listed on *Pre-Filled Obtaining Information Tool* or other sources that don't seem as credible.

Check the websites provided in the *Pre-Filled Obtaining Information Tool Pre-Filled Obtaining Information Tool* to make sure that the links work. Consider adding additional websites that may have been updated more recently.

Before Day 2
Have the Scale Chart poster from Lesson 1 available for the class to further develop.

Lesson 3 • Where We Are Going and NOT Going

Where We Are Going

This lesson is designed to coherently build on ideas related to the following disciplinary core ideas:

- **ESS1.A.4** ~~Other than the hydrogen and helium formed at the time of the Big Bang,~~ nuclear fusion within stars produces all atomic nuclei lighter than and including iron, and the process releases electromagnetic energy. Heavier elements are produced when certain massive stars achieve a supernova stage and explode. (HS-ESS1- 2),(HS-ESS1-3)

Students will figure out in Lesson 6 that the rest of the elements in the Universe were formed during the Big Bang.

- **PS1.C.1:** Nuclear processes, including fusion, ~~fission, and radioactive decays of unstable nuclei,~~ involve release ~~or absorption~~ of energy. The total number of neutrons plus protons does not change in any nuclear process.

Fission is covered in *OpenSciEd Unit C.5: How can chemistry help us evaluate fuels and transportation options to benefit the Earth and our communities? (Fuels Unit)*, and radioactive decay is covered in *OpenSciEd Unit P.2: How forces in Earth's interior determine what will happen to its surface? (Earth's Interior Unit)*. Fusion that absorbs energy will be covered in Lesson 4 of this unit.

- **PS3.D.4** Nuclear fusion processes in the center of the Sun release the energy that ultimately reaches Earth as radiation. (secondary to HS-ESS1-1)
- **ESS1.A.1** The star called the Sun is changing and will burn out over a lifespan of approximately 10 billion years. (HS-ESS1-1)

Students will learn more about the lifecycle of the Sun in Lessons 4 and 5.

Due to the nature of the unit, some students will bring ideas outside of the scope of this unit to the table during the consensus discussion. As long as the fundamental ideas are out on the table (see the assessment callouts), feel free to validate and include these ideas in the class consensus model.

This lesson is designed to coherently build on ideas related to the following science and engineering practice:

- **8.2** Compare, integrate, and evaluate sources of information presented in different media or formats (e.g., visually, quantitatively) as well as in words in order to address a scientific question or solve a problem.

Students began engaging with this element in Lesson 2, when they integrated across photographs and various spectral diagrams. In this lesson, they integrate across more sources that include multiple formats and begin to consider evaluating their credibility. In the next lesson, students will dig deeper into how to evaluate sources.

This lesson is designed to coherently build on ideas related to the following crosscutting concepts:

- **3.1** The significance of a phenomenon is dependent on the scale, proportion, and quantity at which it occurs.
- **5.2** Changes of energy and matter in a system can be described in terms of energy and matter flows into, out of, and within that system.
- **5.5** In nuclear processes, atoms are not conserved, but the total number of protons plus neutrons is conserved.

Students will further engage in CCC 3.1 and 5.2 in Lessons 5 and 7. These ideas also build off their use in previous units.

Students will encounter or co-develop definitions for the following words in this lesson: *fusion, hydrogen, helium, credibility*, or any other words they encountered in their research and found to be unfamiliar. **Do not** post any words or ask students to add them to their Personal Glossaries until after the class has developed a shared understanding of their meaning.

Where We Are NOT Going

This unit addresses the NGSS DCIs related to stellar fusion and stellar evolution by introducing the ideas broadly, but because students will be using different sources to obtain this information, there are no prescribed set of representations, data, or images that students will use to figure this out. For this reason, the unit does not expect students to understand or use Hertzsprung-Russell diagrams, graphs of fusion energies, or diagrams showing stellar convection.

LEARNING PLAN for LESSON 3

1 · NAVIGATE

5 min

MATERIALS: DQB

Navigate with a Turn and Talk. Present **slide A**. Tell students that we had a lot of questions and ideas about energy transfer and matter transformation in guest stars. Say, *We know that forces transfer energy, so we should keep a lookout for ideas about forces, but for now, thinking about energy transfer and matter transformation in stable stars might be a good place to start our investigation.*

Ask students to Turn and Talk about the prompts on the slide:

- *What do we know about how energy transfers in stable stars? How might this be different from the way energy transfers in guest stars?*
- *What do we know about the matter in stable stars and how it changes as energy transfers? How might this be different from the matter in guest stars?*

Have students discuss for a couple of minutes. Ask 1-2 students to share their ideas. Students may not know how energy transfers in stars, or they may bring ideas about fusion, plasma, and electromagnetic radiation. Students should recall from the previous lesson that matter in guests stars looks different from matter in stable stars. Students may already have ideas about supernovae and bring these to the table as well. Accept all ideas without assigning value to one over another.

Present **slide B**. Read the two research questions on the slide. Ask students to look for questions on the DQB that are related to these research questions:

- *Where does the energy come from to power stable stars like our Sun?*
- *How does the matter in stable stars change as energy transfers?*

Break into pairs or small groups for the first research cycle of the unit. Ask each group to spend a minute discussing which research question they are most interested in or assign questions to groups ✱ with the assurance that we will come together and share our findings across both questions. Be sure that at least a couple of groups will research each question.

✱ ATTENDING TO EQUITY

Some students, particularly students with learning differences, below grade-level reading, or students who are emergent multilingual learners, may benefit from additional support. *Pre-Filled Obtaining Information Tool* provides sources for each question. In general, the sources are about at the 11th grade level with each list containing a more challenging text. The reading levels of individual sources are provided on *L3 Research Key*. These are more challenging readings, and parts of them may be difficult for students to access. However, since this is the last unit of the course and it focuses on obtaining information from internet resources, these have been chosen to help bridge students to accessing the wide variety of resources they will find while conducting their own searches in future lessons. Be ready to support students with strategies for reading challenging texts. See suggestions for supporting students is provided in the *OpenSciEd Teacher Handbook: High School Science*.
A differentiated third set of resources is provided on *Alternate Pre-Filled Obtaining Information Tool* that are at a more accessible reading level. These sources do provide less detailed information but still provide enough that students will be able to contribute to the class discussion and engage in comparing and integrating over multiple sources.

2 · INTRODUCE THE PLANNING FOR OBTAINING INFORMATION TOOL

10 min

MATERIALS: *Planning for Obtaining Information Tool*

Introduce the tool. Distribute *Planning for Obtaining Information Tool* and ask students to record the question their group chose in the first row of the tool. Present **slide C** and say, *We're going to use this tool to determine what kinds of resources we need to answer our questions.* Talk through each row as a class and field questions. ✱

✱ ATTENDING TO EQUITY

Fill in the tool in small groups. Present **slide D.** Ask students to begin to fill in the *Planning for Obtaining Information Tool* with their small group. Move around the classroom to provide support. Use probing questions to get students to articulate their thinking, for example:

- *What initial ideas do you have that can help you answer this question?*
- *How will answering that sub-question help you make progress on the larger question?*
- *Why did you choose to list the keywords in that order?*
- *What do you think this means when it says that the sources are credible? How did you take that into account?*

Universal Design for Learning: The initial ideas row on *Planning for Obtaining Information Tool* is meant to value students' funds of knowledge that they bring to the classroom and the research, supporting their *engagement* with it. It also invites students to incorporate other ways of knowing into their sensemaking.

3 · CONSIDER CREDIBILITY

15 min

MATERIALS: *Planning for Obtaining Information Tool*

Hold an initial ideas discussion about what makes a source credible. Present **slide E.** Ask students how they interpreted the word *credible* in the last row of the *Planning for Obtaining Information Tool*. Use the prompts on the slide to draw out more ideas about credibility. ✱✱

- What makes an online source *credible*?
- Why might getting information from a *non*-credible source be a problem?

Look at example websites with the class. Present **slide F.** Open the two websites you prepared ahead of time based on searching one of the research questions (see materials preparation). Use them as examples to consider the credibility of the sources. Point out the "About" sections, if they exist, and the website domains.

ADDITIONAL GUIDANCE

Wikipedia is a free, open-source online encyclopedia that is written and edited by unpaid volunteers. Using Wikipedia as a reference can be a productive way to double check other sources, find new citations to investigate, and get a broad overview of a topic. Before using Wikipedia, students should understand the affordances and limitations.

Affordances:

- **Accessibility:** Wikipedia is free to use and easy to access.
- **Up to date:** Wikipedia articles are constantly being updated and revised by volunteer editors.
- **Bias:** Because of the collaborative nature of Wikipedia, the bias of a single contributor may be balanced by other contributors.
- **Citations:** Many Wikipedia articles include citations to reliable sources, which can be used to verify the accuracy of the information.

Limitations:

- **Accuracy:** Because Wikipedia is written and edited by volunteers, there is no guarantee that all of the information is accurate.
- **Lack of editorial oversight:** Wikipedia does not have a centralized editorial staff, so there is no one to ensure that all of the articles are of high quality.
- **Vandalism:** Wikipedia articles can be vandalized by users, which can lead to inaccurate or misleading information.

Overall, Wikipedia can be a valuable reference tool, but it is important to be aware of its limitations and to use it with caution. When using Wikipedia as a reference, it is important to evaluate the accuracy and reliability of the information and to consult other sources to verify the information.

Ask students if they think the website is credible. Pose the prompt on the slide: *What did you notice about these websites that could help evaluate how credible they are?* Have students share their thoughts. There is no need to come to consensus about this right now.

✱ STRATEGIES FOR THIS INITIAL IDEAS DISCUSSION

Remember that this is an Initial Ideas Discussion, and the goal is not to come to consensus or come up with guidelines. Students will spend more time evaluating sources in the next lesson. The purpose is simply to get ideas about credibility on the table and to consider why this might be important. Take this moment to value the funds of knowledge students bring into the classroom. Especially with the ever-changing internet, there may be some ideas students have about credibility that you wouldn't have considered otherwise.

✱ ATTENDING TO EQUITY

It is important to also recognize that credibility is context-dependent - what is considered credible in the context of western science might not be considered credible in other contexts that are important to students and vice versa.

Emphasize that the goal is not to create a hierarchy of constructs for credibility but rather to clearly establish the importance of context for the assessment of credibility.

Say, *These are some great ideas that will help us as we move forward. We will explore credibility more next lesson. For now, I have collected some credible sources we can start with.*

4 · INTRODUCE THE OBTAINING INFORMATION TOOL AND BEGIN THE FIRST RESEARCH CYCLE

15 min

MATERIALS: *Pre-Filled Obtaining Information Tool*

Orient to the *Pre-Filled Obtaining Information Tool*. Present **slide G.** Distribute one part of *Pre-Filled Obtaining Information Tool* to each student based on which research question they are investigating and introduce the tool to the class. Point out that the handout has a list of credible sources for students to start with.

Allow students to begin their research. Present **slide H**. With the time left in the period, let students begin to work through these sources in their small groups. Encourage them to visit as many as they would like and to add additional sources in the last two rows of the table if they feel comfortable.

Collect *Planning for Obtaining Information Tool* and *Pre-Filled Obtaining Information Tool* and provide written feedback to students on their progress so far before next class.

ASSESSMENT OPPORTUNITY

What to look/listen for: Look for students to work on *Planning for Obtaining Information Tool* and *Pre-Filled Obtaining Information Tool* to:

- Begin considering what makes a source credible (SEP: 8.2)
- Record information from multiple sites (SEP: 8.2)
- Record relevant information to answer the question they chose, including ideas about fusion in the Sun or stars through the lenses of energy and matter. (SEP: 8.2; CCC: 5.2, 5.5; DCI: ESS1.A.4, PS1.C.1, PS3.D.4, ESS1.A.1)

See *L3 Research Key* for more specifics for each source. Note that if students had limited time, they may have only visited one site and may not have covered all the ideas yet. This is a formative moment where you can support individual student engagement moving forward.

What to do: Provide written feedback to students on their planning and notes. Focus on how their notes relate to answering the research questions. Encourage students to use a variety of representations in their notes, including words and pictures. To extend student thinking, suggest ways in which they might be able to make connections between sources as they move forward.

If students need more scaffolding as they research, be ready to work through examples as a class in Lesson 4 before jumping into independent research using the *Evaluating Information Tool*.

Building toward 3.A.1: Compare and integrate information about nuclear processes in stars and how their scale affects their significance from a list of web sources in order to obtain information to address a question and make progress on our models of why and how stars like the Sun change at the beginning and middle of their lives. (SEP: 8.2; CCC: 3.1, 5.2, 5.5; DCI: ESS1.A.4, PS1.C.1, PS3.D.4, ESS1.A.1)

End of day 1

5 · CONTINUE FIRST RESEARCH CYCLE

10 min

MATERIALS: *Pre-Filled Obtaining Information Tool*

Navigate. Return *Planning for Obtaining Information Tool* and *Pre-Filled Obtaining Information Tool* to students and give them a minute to review your feedback before returning to researching.

Give students time to finish their research. If desired, display **slide H** again. Students should get back in their groups and continue moving through the research cycle. Be sure to end research with at least half an hour left in the period for discussion and modeling.

6 · BUILD CONSENSUS IN A SCIENTISTS CIRCLE

15 min

MATERIALS: *Pre-Filled Obtaining Information Tool*, chart paper, chart paper markers, Scale Chart poster from Lesson 1

Come to consensus in a Scientists Circle. Display **slide I.** Guide students in discussion to integrate and compare the information they found across the multiple sources in order to answer the two research questions.

Groups do not need to have researched a question to share ideas that might help answer it. For each question, ask a volunteer to share one of the ideas they uncovered that they think could help us make progress on the question. Recruit students to document the consensus process on chart paper. ✱ The table below provides some example student responses. See *L3 Research Key* for more information on what each source provides.

Suggested prompts	Sample student responses	Notes
Where does the energy come from to power stable stars like our Sun?	Stars' energy comes from nuclear fusion, which creates the energy that gets to Earth as electromagnetic radiation. Fusion is when atoms of one element combine into atoms of another element. Stars mostly fuse hydrogen into helium but can also make other elements. Fusion is possible in stars because they have a lot of mass, and gravity pulls all the mass together and makes things very hot. Hydrogen atoms collide and turn into helium and release a lot of energy. The Sun has about 5 billion years worth of hydrogen left to fuse.	*Students should recall that electromagnetic radiation transfers energy through electric and magnetic fields from OpenSciEd Unit P.5: How do we use radiation in our lives and is it safe for humans? (Microwave Unit).* *Students may include details about conduction and convection, but these concepts are not fundamental to the disciplinary core ideas targeted in this unit, so there is no need to push for them.* *The heating of the particles as they are pushed together by gravity follows the ideal gas law. This was covered in OpenSciEd Unit C.5: How can chemistry help us evaluate fuels and transportation options to benefit the Earth and our communities? (Fuels Unit).* *This model for understanding nuclear processes should remind students of the models we constructed in the OpenSciEd Unit P.2: How forces in Earth's interior determine what will happen to its surface? (Earth's Interior Unit) for radioactive decay.*

✱ STRATEGIES FOR THIS CONSENSUS DISCUSSION

It will be helpful to be explicit with students about your role and their roles in this type of discussion now so that students will come to recognize the goal of the work and your role in the discussion when you say "Consensus" in future lessons. Encourage student-to-student talk with a focus on representing how all the ideas from their group compare to the ideas that others have shared. Encourage restating what others said first before adding on to it or saying whether there is agreement with that idea or not. Students might also use head nods or hand signals to show that they had a similar idea to a classmate's.

As this is the final unit of the course, students should be comfortable with these kinds of discussions and able to take a more substantial role in running the conversation.

Suggested prompts	Sample student responses	Notes
How does the matter in stable stars change as energy transfers?	A process called fusion happens in stars because they are so hot and dense. Fusion changes elements into other elements by combining atoms and releases energy. The Sun and other stable stars mostly fuse hydrogen into helium. Heavier elements, up to iron, can be made in very massive stars. Elements heavier than iron can also be in violent events with stars. Elements from earlier stars make up current stars. The Sun is about halfway through its life cycle. Fusion in stars has formed most of the elements in the universe. Fusion rearranges protons and neutrons into new atoms, and some mass is released as energy, but the total number of protons and neutrons stays the same.	*If students don't raise the idea of conservation of protons and neutrons, point them towards the diagrams of fusion and ask them to consider the dots that represent protons and neutrons. Pose the question: How is matter conserved during fusion? Students may bring up the term supernovae when they talk about heavier elements being made. Encourage them to write it down to investigate later but do not connect this with guest stars, as this will be done in a future lesson.* *Again, this idea should remind students of matter changes in radioactive decay.* *$E=mc^2$ can be used to calculate how much energy is released based on how much matter is unaccounted for.* *We encourage you to use the names of these two elements to talk about the matter in a star throughout this unit, as they are fundamental to understanding stellar processes and connecting ideas to chemistry.*

ADDITIONAL GUIDANCE

Make sure to make clear the distinction between a nuclear reaction and a chemical reaction. You can lean on ideas from *OpenSciEd Unit P.2: How forces in Earth's interior determine what will happen to its surface? (Earth's Interior Unit)* to remind students that changes to atomic nuclei are different from changes to chemical compounds because they actually change the elements themselves. Be sure to highlight the idea that even though the atoms are changing, the total number of protons plus neutrons stays the same in *all* nuclear processes.

Consider scale. Present **slide J** and ask students to discuss the question on the slide: *How does something as small as a fusion reaction between two hydrogen atoms produce sufficient energy to power a star?*
Encourage students to continue the Scientists Circle format for this discussion, which focuses on student-to-student talk. Look for students to bring up ideas about scale, such as how big stars are, and thus how much fuel there is, or how a single reaction multiplied countless times can create a significant effect. Highlight these ideas and suggest that we expand upon the scale ideas from the anchor.

Update the Scale Chart. Display the Scale Chart poster from Lesson 1 and say, *Let's add these ideas to our scale chart from our original modeling. What type of scale have we just been discussing as significant for fusion to fuel stars?*

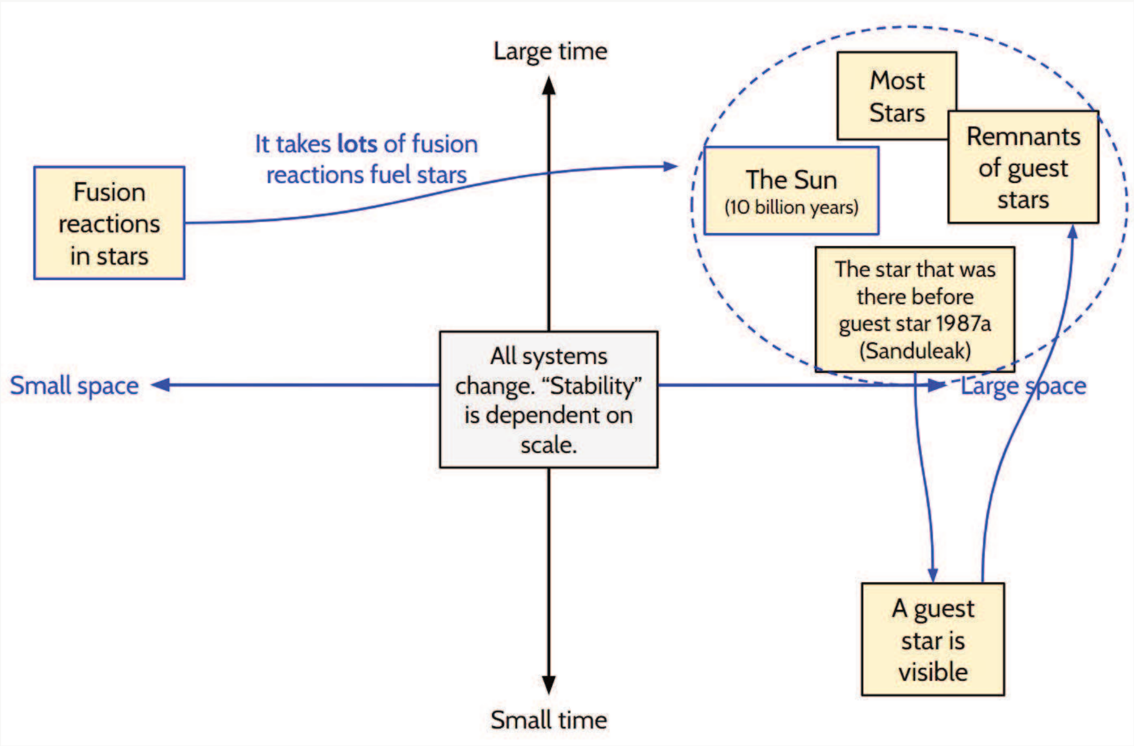
Look for students to say that the type of scale is spatial or to do with size. Recall how the scale chart in *Earth's Interior Unit* had both time and spatial scales and add a horizontal axis to the current scale chart if necessary. Ask students to take over the discussion and manipulation of where the phenomena sticky notes from the time scale belong along the space scale.

Take this opportunity to fill in anything that might be missing from Lesson 1. Once the existing phenomena have been adjusted for both scales, suggest that students add the new phenomena from this lesson to the chart, such as fusion and the Sun as an example of a stable star.

Look for students to add fusion as a super-small space scale. They may choose to put fusion in either small time, large time, or both, depending on if they mean for an individual pair of atoms or the overall process of fusing hydrogen in stars.

Take a moment to draw out that the sources gave clues about the timescale for the life of the Sun. If students didn't pick up on these details, it's okay. Say, *The sources told us that the Sun has been fusing hydrogen for about 5 billion years and has about 5 billion years left.* Encourage them to add this detail to the scale chart and use it as a kind of reference in the time scale.

Make connections between small-scale fusion and energy of a star. Once students have added fusion to the scale chart, re-pose the question on **slide J.** They should say something about the huge quantity of reactions that must be happening within a star since it's so massive and releases so much energy. Suggest the students document their answer to this on the scale chart. An example resulting scale chart is shown below. Blue shows suggested additions in this lesson.



7 · MODELING OUR SUN, A STABLE STAR

10 min

MATERIALS: copy paper, chart paper, chart paper markers

Individual modeling. Present **slide K**. Read the text on the slide: *Use the ideas we obtained from our sources to develop a model that explains:*

- *What is happening with matter and energy within stars?*
- *How might this help us make progress on our investigation of guest stars?*

Distribute copy paper to each student and give students about five minutes to model on their own. They can do this in the Scientists Circle because we will come back together and do some consensus modeling immediately afterward. Encourage students to incorporate the ideas that were obtained from integrating across our multiple sources into their models.

In order to individually assess and provide feedback, collect the individual models at the end of the class.

ASSESSMENT OPPORTUNITY

What to look/listen for: Look for students' models to include:

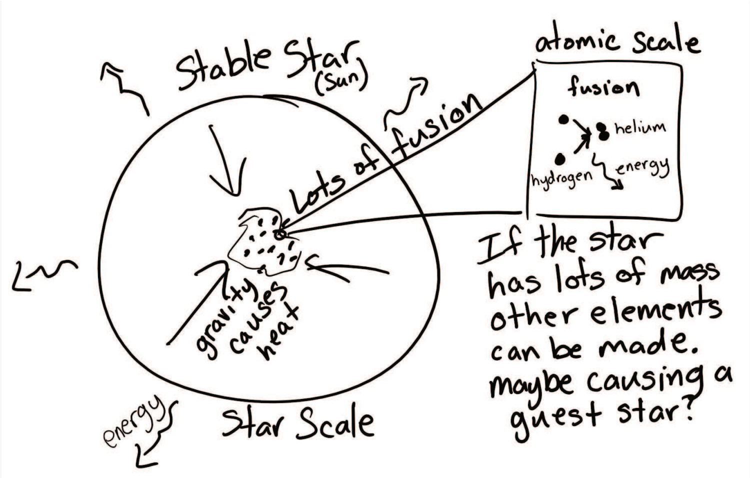
- Integrated information from across multiple sources of information as well as the class discussion. (SEP: 8.2)
- High heat in the core of the Sun causing particle nuclei to collide and fuse together. (CCC: 5.2; DCI: ESS1.A.1)
- Particle nuclei fusing and releasing energy. (CCC: 5.5, 5.2; DCI: ESS1.A.4, PS1.C.1, PS3.D.4)
- Energy transferring out of the Sun, including towards Earth. (CCC: 5.2; DCI: ESS1.A.4, PS3.D.4)
- Two hydrogen atoms fuse to become one helium atom. (CCC: 5.5; DCI: PS1.C.1, ESS1.A.1)
- New elements being made in stars and the possibility for heavier elements to be made if the star is massive enough. (DCI: ESS1.A.4)
- The total number of protons plus neutrons are conserved but atoms are not. (CCC: 5.5, DCI: PS1.C.1)
- A large number of tiny-scale fusion reactions occurring inside a star are responsible for the enormous amounts of energy produced at the scale of the Sun. (CCC: 3.1, DCI: PS1.C.1)

What to do: Collect students' individual models to provide feedback on how well they represent the vast number of ideas within their model. Highlight the connections between matter and energy and the big ideas that students will need to put the pieces together when modeling feedback loops in Lesson 5.

For students who struggled with individual modeling, consider providing an opportunity for them to revise their models.

Building toward 3.A.2: Compare and integrate information about nuclear processes in stars and how their scale affects their significance from a list of web sources in order to obtain information to address a question and make progress on our models of why and how stars like the Sun change at the beginning and middle of their lives. (SEP: 8.2; CCC: 3.1, 5.2, 5.5; DCI: ESS1.A.4, PS1.C.1, PS3.D.4, ESS1.A.1)

Consensus modeling. Present **slide L.** Ask three volunteers to stand up and share their models, either by standing at the front of the circle or by slowly walking it around the circle. Then ask a volunteer to share something they saw in all three models that was similar to what they had. Ask the class if they agree and then have a student begin recording a consensus model on chart paper. Make sure the model includes most of the ideas the class came up with about how stars produce energy and change matter. Use the individual modeling assessment guidance above to inform the consensus model as well. The model may look something like the image below.



ADDITIONAL GUIDANCE	When discussing the elements that are fused in more massive stars, we discuss elements that are “heavier” than helium, “up to” iron. This language is based on elements’ atomic weights and arrangement on the periodic table of elements. Consider providing the *Periodic Table* from Lesson 2 to students to support their sensemaking.

8 · KEEP TRACK OF OUR IDEAS

5 min

MATERIALS: science notebook, *Progress Tracker*

Add new words to Personal Glossaries. Display **slide M.** Ask students if there are words they should add to their Personal Glossaries. They may want to add *fusion, hydrogen*, *helium*, or any other words they encountered in their research and found to be unfamiliar. There may also be words they have encountered but do not know what they mean yet. Encourage students to add questions about these to the DQB.

Record ideas in Progress Trackers. Ask students if they have made progress on making sense of guest stars and stable stars. Have them take out *Progress Tracker*. Ask them to record what they have figured out in their Progress Trackers. They can use the class consensus model and important ideas charts. Encourage them to use any combination of words, drawings, or symbols. Ideas they may record include:

- Stars are driven by fusion. Hydrogen fuses together. Fusion releases energy.
- The energy transfers to the outside of the star and then radiates into space. It reaches us as electromagnetic radiation.
- Pressure inward from gravity pushes particles together, causing fusion. That pressure must be big enough to overcome electric repulsion forces between atoms. This is why stars are so massive.
- Fusion creates new elements. In most stars, hydrogen becomes helium. Other elements can be made in more massive stars or at the end of a star’s life.
- Protons and neutrons are conserved in fusion, but the number of atoms changes.

9 · NAVIGATE

5 min

MATERIALS: 3x3 sticky notes, permanent marker, DQB

Add questions to the DQB. Present **slide N.** Ask students to consider all the information we have collected across multiple sources and what new questions they have. Give students a few minutes to record new questions on sticky notes, then allow each student to read their question and add it to the DQB. Ask them to consider if their question is more about matter, energy, or forces and to place their question in the appropriate category on the board. As they answer their questions, their answers may be associated with a different category, and they can move their question to the appropriate category later. If students have similar questions to the one read aloud, they can put similar questions together. ✱

Before students leave, highlight questions students have about what happens when stars run out of hydrogen, explosions, supernovae, or how stars die. Say, *Today we figured out what the energy source is for stars. But we still have questions about what happens when that energy runs out. Let's investigate this further next time.*

✱ ATTENDING TO EQUITY

Revisiting the Driving Question Board is important for students to feel as though their questions are valued and recognized. While not all questions will have been addressed (it's more likely that 50–75 percent will be at least partially answered by the end of the unit), this helps students see the hard work that they have done to answer many of their own questions.

Additional Lesson 3 Teacher Guidance

SUPPORTING STUDENTS IN MAKING CONNECTIONS IN ELA	**CCSS.ELA-LITERACY.RI.11-12.7** Integrate and evaluate multiple sources of information presented in different media or formats (e.g., visually, quantitatively) as well as in words in order to address a question or solve a problem. Students gather and evaluate sources of information from online media. The sources of information in different formats have to be integrated in order to address the research questions.

LESSON 4: How does running out of fuel cause a star to change?

PREVIOUS LESSON *We considered how studying energy and matter in stable stars could help us answer our questions about guest stars. We used the Planning for Obtaining Information Tool to plan our research and the Obtaining Information Tool to keep track of what we found out. We came to consensus around the answers to our research questions and recorded our ideas in our Progress Trackers and Personal Glossaries. We revisited questions on the DQB.*

THIS LESSON

INVESTIGATION

3 days

NASA, ESA, CSA, and STScI

We model the macro forces of a star to help us figure out what keeps stars stable and make sense of the balance between gravity and outward pressure in stable stars. We develop research questions and are introduced to a new tool: the Evaluating Sources of Information Tool. We gather information and communicate our findings in a gallery tour. We come to consensus on what causes stars to remain stable or become unstable and change and record those ideas in our Progress Trackers.

NEXT LESSON *We will create a Gotta-Have-It Checklist to explain what cause-effect relationships occur within stars. We will model the feedback loop that keeps stars stable and what happens when this loop is disrupted. We will update the Scale Chart and revisit the DQB.*

BUILDING TOWARD NGSS

HS-ESS1-1, HS-ESS1-2, HS-ESS1-3, HS-PS1-8

WHAT STUDENTS WILL DO

4.A Ask questions that arise from our research on fusion and from modeling the forces in stars when they are stable to clarify and seek additional information about how stars change when their fuel runs out. (SEP: 1.1, 1.4; CCC: 5.2, 7.1, 7.3; DCI: ESS1.A.4, PS3.D.4)

4.B Gather, read, evaluate, and integrate information from multiple authoritative internet sources, assessing the evidence and usefulness of each source in answering our questions about how stars (including our Sun) remain stable and can become unstable over their life cycles and communicate the information with graphics and text. (SEP: 8.2, 8.3, 8.5; CCC: 7.1, 7.3; DCI: ESS1.A.1, ESS1.A.4, PS1.C.1)

WHAT STUDENTS WILL FIGURE OUT

- Stars exist because there is a balance (or equilibrium) between gravity forces pushing inward and the outward pushing forces of the hot, fast moving particles at the center of the star (due to energy released by fusion).
- A feedback loop between gravity and fusion maintains this equilibrium.
- Stars eventually run out of hydrogen in their cores. When there is not enough concentration of particles to keep fusing heavier elements, the equilibrium is broken, and the star will die.
- What happens to a star when it dies depends on its mass. More massive stars run out of fuel faster because their gravity will cause the concentration of particles in the core to be higher, increasing fusion rates.
- When a star like the Sun runs out of hydrogen to produce energy, the core will cool and condense. The Sun will become a red giant because of a multi-step process kicked off by this cooling and condensing and eventually fade away.
- Massive stars can fuse heavier elements, up to iron for super-massive stars.
- When a very massive star fuses iron in its core, the reaction will no longer release energy, and there will not be enough outward force to balance gravity, disrupting the stable feedback loop. The star collapses and bounces back in what is called a supernova.
- Supernovae transfer a lot of energy into space. What ancient astronomers called “guest stars” are actually the light that results from this transfer of energy.

Lesson 4 • Learning Plan Snapshot

Part	Duration		Summary	Slide	Materials
1	5 min		**NAVIGATE** Recap the last lesson in pairs.	A	
2	20 min		**MODEL STABILITY IN STAR SYSTEMS** Come to consensus on the macro forces of a star to discover hydrostatic equilibrium.	B-E	chart paper, chart paper markers
3	10 min		**DEVELOP RESEARCH QUESTIONS** Identify questions to help make progress on figuring out about stability and change in stars.	F	forces model and questions from previous discussion
4	10 min		**PREPARE FOR ANOTHER RESEARCH CYCLE** Support students in choosing a research question and completing the *Evaluating Sources of Information Tool*. Introduce the *Evaluating Online Sources Overview*.	G-I	new copies of *Planning for Obtaining Information Tool*, *Evaluating Online Sources Overview*, *Evaluating Sources of Information Tool*
					End of day 1
5	25 min		**BEGIN SECOND RESEARCH CYCLE WITH EVALUATE SOURCES AND OBTAIN INFORMATION** Support students as they evaluate resources and record important ideas in the second research cycle.	J	*Obtaining Information Tool*, *Evaluating Sources of Information Tool*, *Evaluating Online Sources Overview*
6	5 min		**INTRODUCE THE POSTER ACTIVITY** Discuss the importance of how we communicate ideas and the requirements for the research poster.	K-L	chart paper, chart paper markers
7	15 min		**CONTINUE SECOND RESEARCH CYCLE** Begin the second research cycle to gather and prepare to communicate information about what happens to a star when the fuel runs out.	L	*Obtaining Information Tool*, chart paper, chart paper markers, *Evaluating Sources of Information Tool*, *Evaluating Online Sources Overview*
					End of day 2
8	10 min		**FINISH THE SECOND RESEARCH CYCLE** Finish research and complete research posters.	M	*Obtaining Information Tool*, research posters started the previous day, chart paper markers, *Evaluating Sources of Information Tool*, *Evaluating Online Sources Overview*
9	15 min		**GALLERY TOUR** Conduct a gallery tour to share research posters.	N	completed research posters, tape
10	15 min		**COME TO CONSENSUS ON WHAT WE FIGURED OUT** Come to consensus around what happens to a star when the fuel runs out.	O	chart paper, chart paper markers, stable star model from day 1

Part	Duration		Summary	Slide	Materials
11	5 min		**KEEP TRACK OF OUR IDEAS AND NAVIGATE** Keep track of our ideas in our Progress Trackers and Personal Glossaries and then complete an exit ticket.	P-Q	*Progress Tracker*, paper for exit tickets

End of day 3

Lesson 4 • Materials List

	per student	per group	per class
Lesson materials	• science notebook • *Obtaining Information Tool* • *Progress Tracker* • paper for exit tickets	• new copies of *Planning for Obtaining Information Tool* • *Evaluating Online Sources Overview* • *Evaluating Sources of Information Tool* • chart paper • chart paper markers • research posters started the previous day • completed research posters	• chart paper • chart paper markers • forces model and questions from previous discussion • tape • stable star model from day 1

Materials preparation (20 minutes)

Review teacher guide, slides, and teacher references or keys (if applicable).

Make copies of handouts and ensure sufficient copies of student references, readings, and procedures are available.

Make copies of the handout for this lesson:

- New copies of *Planning for Obtaining Information Tool* from Lesson 3 (1 per pair)
- *Evaluating Online Sources Overview* (1 per pair)
- *Evaluating Sources of Information Tool* (1 per pair)
- *Obtaining Information Tool* (1 per student)

Three-hole-punch all the handouts so they can be added to students' notebooks.

Prepare for students to be working independently on the internet in small groups for much of this lesson.

Prepare paper for exit tickets at the end of day 3.

Lesson 4 • Where We Are Going and NOT Going

This lesson is designed to coherently build on ideas related to the following disciplinary core ideas:

- **ESS1.A.4** ~~Other than the hydrogen and helium formed at the time of the Big Bang~~, nuclear fusion within stars produces all atomic nuclei lighter than and including iron, and the process releases electromagnetic energy. ~~Heavier elements are produced when~~ certain massive stars achieve a supernova stage and explode. (HS-ESS1- 2),(HS-ESS1-3)

The production of elements during the Big Bang will be covered in Lesson 6. The production of elements heavier than iron in supernovae may or may not come up in students' findings in this lesson. This idea was initially mentioned in Lesson 3 and will be revisited in Lesson 5.

- **PS3.D.4** Nuclear fusion processes in the center of the Sun release the energy ~~that ultimately reaches Earth as radiation~~. (secondary to HS-ESS1-1)

The idea that the energy from the Sun reaches Earth as radiation was covered in Lesson 3.

- **ESS1.A.1** The star called the Sun is changing and will burn out ~~over a lifespan of approximately 10 billion years~~. (HS-ESS1-1)

And the lifespan of the Sun was initially mentioned in Lesson 3 and will be revisited in Lesson 5.

- **PS1.C.1:** Nuclear processes, including fusion, ~~fission, and radioactive decays of unstable nuclei,~~ involve release ~~or~~ absorption of energy. ~~The total number of neutrons plus protons does not change in any nuclear process~~.

This lesson builds on the ideas developed in Lesson 3 and adds the idea that energy can be absorbed during fusion within the discussion of stars fusing iron. Lesson 3 covered the conservation of protons plus neutrons, radioactive decay was covered in *OpenSciEd Unit P.2: How forces in Earth's interior determine what will happen to its surface? (Earth's Interior Unit)*, and fission was covered in *OpenSciEd Unit C.5: How can chemistry help us evaluate fuels and transportation options to benefit the Earth and our communities? (Fuels Unit)*.

This lesson is designed to coherently build on ideas related to the following science and engineering practices:

- **1.1** Ask questions that arise from careful observation of phenomena or unexpected results to clarify and/or seek additional information.
- **1.4** Ask questions to clarify and refine a model, an explanation, or an engineering problem.

These elements have mostly been used in the context of the Driving Question Board across the course. In this lesson, students extend their engagement with these elements within the context of crafting research questions that they then use to do internet research.

- **8.2** Compare, integrate, and evaluate sources of information presented in different media or formats (e.g., visually, quantitatively) as well as in words in order to address a scientific question or solve a problem.

This element has been developed across Lessons 2 and 3. This lesson culminates students' engagement with this element through having them do a more detailed evaluation of sources they find themselves as well as continuing to compare and integrate across multiple sources to answer their scientific questions.

- **8.3** Gather, read, and evaluate scientific and/or technical information from multiple authoritative sources, assessing the evidence and usefulness of each source.

This lesson introduces students to gathering their own sources of information and carefully evaluating their credibility and usefulness. Students will further engage in this practice in Lesson 6 within a more open-ended research cycle about the Big Bang.

- **8.5** Communicate scientific ~~and/or technical~~ information or ideas (e.g., about phenomena ~~and/or the process of development and the design and performance of a proposed process or system~~) in multiple formats (i.e., ~~orally~~, graphically, textually, ~~mathematically~~).

Creating posters to communicate their research findings is an initial step towards engaging in this element. In this lesson, students will present their research findings using graphics and text on posters. In Lesson 6, students will have a chance to further develop their engagement with this practice, supported by the use of the *Planning for Communicating Information Tool*. They will then communicate research findings in a format of their choice.

This lesson is designed to coherently build on ideas related to the following crosscutting concepts:

- **5.2** Changes of energy and matter in a system can be described in terms of energy and matter flows into, out of, and within that system.

Students continue to consider, analyze, and ask questions about how matter and energy are changing within star systems to understand the larger questions about what causes guest stars.

- **7.1** Much of science deals with constructing explanations of how things change and how they remain stable.

This lesson builds on the big ideas of stability and change that frame this unit, considering what causes stars to remain stable or become unstable and change. This will continue to be developed in Lesson 5 when we put the pieces together.

- **7.3** Feedback (negative or positive) can stabilize or destabilize a system.

This lesson introduces the idea of feedback loops. In this lesson, the concepts are developed within student research. Hopefully this research will bring the term *feedback* into conversation naturally. If it doesn't, there is a moment towards the end of the lesson to introduce it within the concepts that students have discussed in the Consensus Discussion. The term and concept will be further solidified in Lesson 5, when students model feedback loops for star systems.

Students will encounter or co-develop definitions for the following words in this lesson: *supernova, equilibrium, feedback loop*, or any other words they encountered in their research and found to be unfamiliar. **Do not** post any words or ask students to add them to their Personal Glossaries until after the class has developed a shared understanding of their meaning.

LEARNING PLAN for LESSON 4

1 · NAVIGATE

5 min

MATERIALS: None

Remind ourselves what we were wondering and how that could help us make progress on our questions about the guest stars. Present **slide A**. Have students turn and talk about the prompts on the slide for about two minutes and then elicit ideas as a class.

Suggested prompt	Sample student response
What is the fuel for a star?	Hydrogen Fusion Matter lost in fusion
What questions did we have last time about what would happen if a star ran out of fuel?	What would happen to it? Could it become a guest star? Explode?
How could investigating what happens when stars run out of fuel help us make progress on our questions about the guest star?	Maybe when a star runs out of fuel, it becomes a guest star.

2 · MODEL STABILITY IN STAR SYSTEMS

20 min

MATERIALS: chart paper, chart paper markers

Motivate modeling forces within stars. Present **slide B**. Pose the questions on the slide to the class to motivate modeling forces within stars:

Suggested prompt	Sample student response
Does our model explain what keeps a star stable or makes it unstable?	No Some of us talked about unstable stars fusing different matter than stable stars. Maybe that has something to do with it.
What perspective could we add that might help us explain stability?	Forces Maybe something to balance out the energy made by fusion?

✱ SUPPORTING STUDENTS IN DEVELOPING AND USING STABILITY AND CHANGE

This is an opportunity to use the language of stability and change as students discuss what they think will happen to the star. This will support the connections they make across phenomena. Students will get a chance to reflect on stability and change at the end of this lesson. Point out that wondering about the stability and change of a star is consistent with a lot of what we considered

Model forces in a stable star. Present **slide C.** Say, *Let's start modeling a star when it is stable so that we can use that model to make predictions about what could happen to make it no longer stable*. Sketch a large circle at the front of the room. Tell students that it is the star system.

Pose the first question on the slide: *Where is fusion taking place?* Look for ideas about the center of the star, or the core. Draw a second circle inside the center of the first to represent the place where fusion is taking place. Label this circle "Fusion." Label the larger circle "No fusion."

Draw out ideas about gravitational forces using the first question on the slide. Ask students why fusion only happens at the center of the star. Look for ideas about gravity, pressure, and mass. Use probing questions to clarify students' ideas and draw out ideas about gravitational forces acting on the matter at the core of the star, for example:

- *Where is that pressure coming from?*
- *What forces are important when something has a lot of mass?*
- *What direction will those gravitational forces be on the matter at the core of the star?*

Use arrows to show the direction of gravitational forces inside the star and label them. Ask students if they agree with the way you have modeled gravitational forces.

Draw out ideas about pressure forces using the other questions on the slide. Then ask students the second prompt on the slide about the effect of fusion on the matter at the core of the star. Use probing questions to get students to describe the particle-level interactions that cause pushing outward on the matter in the star.

Suggested prompt	Sample student response
What will the effect of fusion be on the matter in the center of the star at this scale?	It will make the matter hot. It will release a lot of energy.
What does this look like on a particle scale when matter is hot or has a lot of energy?	The particles move around a lot. The particles wiggle.
How will this look on a much bigger scale, the scale of the core of a star?	The core will expand. The gasses expand and push outward.
How will these changes affect the matter in the rest of the star further out from the core?	The matter in the core will push outward on the matter above it in the star.

Use arrows to show the direction of pushing or pressure forces from fusion inside the star and label them. Ask students if they agree with the way you have modeled these forces.

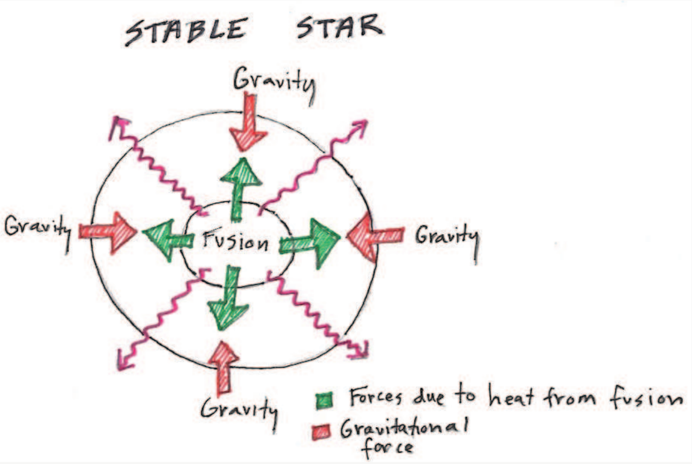
Keep track of questions that emerge from modeling. As you model, record any questions students have at the front of the room. Some questions students might have are:

- Which part of the star is more dense?
- Could fusion happen in the outside of the star if the star is big enough?
- Do bigger stars have more fusion?

Your model should look something like the example at right.

with other phenomena and that much of science deals with explaining stability and change.

Forecast a feedback loop. Present **slide D**. Use the first prompt on the slide to ask students what will happen to the forces causing fusion if the core of the star expands and pushes outward. Some students might suggest that there will not be as much pressure on the particles, so fusion might slow down. If students don't get there right now, do not play guess what's in my head. Say, *As the core of the star expands, the concentration of hydrogen particles decreases, so fusion slows down, and the core will contract a little bit. That way if the star gets too hot, it has a way of cooling itself down.* Do not worry about establishing conceptual understanding around this idea right now, but put it on the table in case students want to ask questions about it for their research. ✱



Pose the second prompt on the slide: *Will this help the star stay stable or make it unstable? Why do you think that?* Look for students to talk about forces balancing and changing and impacting each other. Again, don't worry about building detailed understanding yet, but try to seed the ideas of one change causing other changes that balance out and keep things stable or being unstable if there isn't anything that can change in response. If students bring up the term *feedback*, highlight this, but do not provide the term yet.

Consider what will happen to the forces in our model if there is no more hydrogen. Present **slide E**. Ask students what we were wondering at the start of this lesson. Students should say that we were wondering what would cause a stable star to become unstable.

Then pose the first question on the slide: *Can our model make predictions that will help us answer these questions?*
Look for ideas about the star running out of fuel and no longer having the outward pressure forces from fusion energy. Use additional probing questions to support this line of reasoning if necessary, such as:

- *Since the energy of stars comes from fusing hydrogen, what do you think would happen if the star ran out of hydrogen?*
- *What will happen to the forces that we modeled if the star runs out of fuel?*
- *Will it affect the gravitational forces?*
- *How about the pressure forces?*

Listen for the suggestion that the forces we modeled pointing outward from the center of the star will disappear. Use a different color to cross out these forces on the model you made or erase them if using a whiteboard.

Ask, *So what will happen to the star if these forces are not balancing each other anymore?* Look for ideas about the star exploding, collapsing, shrinking, etc.

Consider what we need to know. Pose the final prompt on the slide: *What else do we need to know to answer our question?* Look for ideas about how much hydrogen is in a star, whether or not a star can fuse helium, if a star can explode, etc. Record any new questions at the front of the room. Then say, *It sounds like we have more research to do about stars running out of fuel.*

3 · DEVELOP RESEARCH QUESTIONS

10 min

MATERIALS: science notebook, forces model and questions from previous discussion

Brainstorm research questions using the list we made. Present **slide F**. As a class, look back to the list of questions we made as we modeled and decide which ones will help us make progress on figuring out what causes stars to remain stable or become unstable and change. Add any additional questions we would like to research related to the fuel running out in a star. Some questions that students might come up with are:

- What happens if a star runs out of hydrogen?
- Could the star fuse helium?
- Do all stars fuse elements at the same rate?
- Will the Sun collapse when it runs out of hydrogen?
- Will a star become a black hole when it runs out of hydrogen?
- Which part of a star is more dense?
- Will a star explode if it runs out of hydrogen?
- Will it collapse, and if so, how small can it get?
- Will the Sun run out of hydrogen?
- How much fuel does our Sun have left?
- How does the mass of a star affect what happens to it?
- What's the heaviest element that can be fused in a star?

ADDITIONAL GUIDANCE	As some of the disciplinary core ideas we are targeting with this lesson focus on the Sun specifically, encourage some groups to continue using the Sun as a focal example of a stable star. This should allow connections to be made specifically to details of the Sun as well as comparisons between the Sun and stars much more massive than the Sun.
ASSESSMENT OPPORTUNITY	**What to look/listen for:** • Questions that seek additional information about what we don't know about fusion and the forces inside of stars, including the Sun. (SEP: 1.1, 1.4; DCI: ESS1.A.4, PS3.D.4) • Questions about what changes in matter, energy, and forces might keep a star stable or cause a stable star to become unstable. (SEP: 1.1, 1.4; CCC: 5.2, 7.1, 7.3) • Questions that will help us understand what happens to stars when their fuel runs out, including what elements can be fused within stars. (SEP: 1.1, 1.4; DCI: ESS1.A.4, PS3.D.4) **What to do:** Direct students' attention to the models they recorded in their science notebooks to help them develop more focused questions about parts of the model that we don't understand. If you wish to assess students' questions individually, consider using a format similar to the Driving Question Board, where students write questions on sticky notes and put their initials on the backs. **Building Toward 4.A** Ask questions that arise from our research on fusion and from modeling the forces in stars when they are stable to clarify and seek additional information about how stars change when their fuel runs out. (SEP: 1.1, 1.4; CCC: 5.2, 7.1, 7.3; DCI: ESS1.A.4, PS3.D.4)

4 · PREPARE FOR ANOTHER RESEARCH CYCLE

10 min

MATERIALS: new copies of *Planning for Obtaining Information Tool*, *Evaluating Online Sources Overview*, *Evaluating Sources of Information Tool*

Use the *Planning for Obtaining Information Tool* in partners. Present **slide G**. Distribute blank copies of the *Planning for Obtaining Information Tool*. Organize students into pairs. Ask students to choose a question they want to research with their partner and record it in the *Planning for Obtaining Information Tool*. Then direct them to complete the tool.

Introduce the *Evaluating Online Sources Overview*. Say, *Last lesson and on our Planning for Obtaining Information Tool, we considered how to find credible resources, but let's dig a bit more into how to evaluate sources that we do find.* Present **slide H.** Distribute *Evaluating Online Sources Overview* to each partner pair. Have students read through each row of *Evaluating Online Sources Overview* with a partner, responding to the questions on the slide:

- *Which categories do you think will be easy to figure out?*

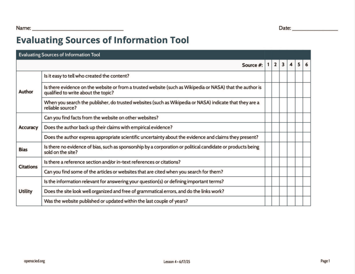
✱ SUPPORTING STUDENTS IN ENGAGING IN OBTAINING, EVALUATING, AND COMMUNICATING INFORMATION

The resources in this unit for evaluating sources are designed to align with the science and engineering practices of

- *Which categories do you think will be more difficult?*
- *When might it be important to consider some of these categories outside of school?*

Ask students to quickly share which categories they discussed and why. Then distribute *Evaluating Sources of Information Tool*.

Present **slide I.** Use the slide to introduce the *Evaluating Sources of Information Tool* ✱ and field student questions about how we will use it next class to structure our research.


Name: ______________ Date: ______________

Evaluating Sources of Information Tool

Evaluating Sources of Information Tool							
	Source #:	1	2	3	4	5	6
Author	Is it easy to tell who created the content?						
	Is there evidence on the website or from a trusted website (such as Wikipedia or NASA) that the author is qualified to write about the topic?						
	When you search the publisher, do trusted websites (such as Wikipedia or NASA) indicate that they are a reliable source?						
Accuracy	Can you find facts from the website on other websites?						
	Does the author back up their claims with empirical evidence?						
	Does the author express appropriate scientific uncertainty about the evidence and claims they present?						
Bias	Is there no evidence of bias, such as sponsorship by a corporation or political candidate or products being sold on the site?						
Citations	Is there a reference section and/or in-text references or citations?						
	Can you find some of the articles or websites that are cited when you search for them?						
Utility	Is the information relevant for answering your question(s) or defining important terms?						
	Does the site look well organized and free of grammatical errors, and do the links work?						
	Was the website published or updated within the last couple of years?						

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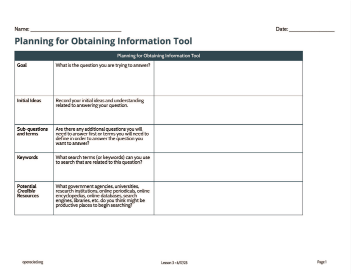
Name: ______________ Date: ______________

Planning for Obtaining Information Tool

Planning for Obtaining Information Tool		
Goal	What is the question you are trying to answer?	
Initial Ideas	Record your initial ideas and understanding related to answering your question.	
Sub-questions and terms	Are there any additional questions you will need to answer first or terms you will need to define in order to answer the question you want to answer?	
Keywords	What search terms (or keywords) can you use to search that are related to this question?	
Potential *Credible* Resources	What government agencies, universities, research institutions, online periodicals, online encyclopedias, online databases, search engines, libraries, etc. do you think might be productive places to begin searching?	

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evaluating sources and scientific information from multiple authoritative sources and assessing the evidence and usefulness of each source. In *OpenSciEd Unit P.5: How do we use radiation in our lives and is it safe for humans? (Microwave Unit)*, we used *Evaluating Information Checklist* to evaluate the validity and reliability of information within texts. These tools are similar but have distinct purposes.

ADDITIONAL GUIDANCE

Consider reaching out to a school or local librarian about additional resources available for supporting students in conducting research, search engine logic tools, evaluating resources, incorporating AI into research processes, or citing references.

ALTERNATE ACTIVITY

If some of your students need extra support accessing textual information, prepare some more accessible resources ahead of next class. Search for relevant sources to the research questions the class developed and look for sources such as videos, resources written at a more accessible reading level, or resources that incorporate more visual representations that can supplement the textual information.

End of day 1

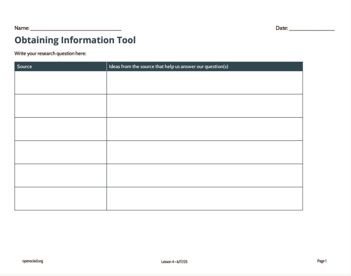
5 · BEGIN SECOND RESEARCH CYCLE WITH EVALUATE SOURCES AND OBTAIN INFORMATION

25 min

MATERIALS: *Obtaining Information Tool*, *Evaluating Sources of Information Tool*, *Evaluating Online Sources Overview*

Continue the second research cycle. Present **slide J**. Distribute blank copies of *Obtaining Information Tool* to each student and ask students to get out *Planning for Obtaining Information Tool* and *Evaluating Online Sources Overview* from last class. Give students time to begin the research cycle with their partners, keeping track of ideas in the table in *Obtaining Information Tool* and evaluating sources using *Evaluating Sources of Information Tool*.

Move around the classroom to support students as they evaluate resources ✱ and record important ideas. See the assessment guidance at the end of day 2 for ideas on how to assess and support students as they work. If you see a student using or encountering the term *feedback*, ask probing questions and encourage them to figure out what that means in order to share with the class.


Name: ______________ Date: ______________

Obtaining Information Tool

Write your research question here:

Source	Ideas from the source that help us answer our question(s)

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✱ ATTENDING TO EQUITY

Supporting emergent multilingual learners: Adding the additional layer of using *Evaluating Sources of Information Tool* and *Evaluating Online Sources Overview* to evaluate sources may be overwhelming for some students. Consider forming a study group that you guide through examples of how to navigate sources while using these evaluation tools.

6 · INTRODUCE THE POSTER ACTIVITY

5 min

MATERIALS: science notebook, chart paper, chart paper markers

Consider why it is important to be intentional in how we communicate ideas. Present **slide K**. Read the text at the top of the slide: *We will be creating posters to communicate our ideas with each other as a scientific community.* Forecast that we will make posters and share them in a gallery tour. Then have students stop and jot about the prompts on the slide:

- *Why is it important to be intentional in how we communicate scientific ideas?*
- *Think about your experiences in and outside of school where you have communicated with others.*

What characteristics define and help facilitate successful communication?
Have a few students share. Accept all ideas.

Introduce the poster requirements. Use **slide L** to present students with the requirements for the poster they will make for the gallery tour. Provide chart paper and markers to each partner pair. Point out to students that the audience for this presentation will be their peers and that this is important to keep in mind.

Explain that posters will need to include:

- Their research question clearly printed.
- An answer to the research question, using a combination of words, symbols, and drawings. ✱ Remind students to make sure to label everything clearly.
- An explanation of how answering your research question helps us make progress on our question about what causes stars to remain stable or become unstable and change.
- Sources that students used. Provide guidance for students about how you would like them to cite their sources.

ADDITIONAL GUIDANCE

Consider collaborating with an English teacher to find out how students are expected to cite their sources in other classes, and be consistent.

If your school uses APA style, you can ask students to cite each online resource like this:

- Author last name, first initial. (publishing date). Title. Publisher. Web address.

Example:

- Slat, B. (2019, April 10). Whales likely impacted by Great Pacific garbage patch. The Ocean Cleanup. https://www.theoceancleanup.com/updates/whales-likely-impacted-by-great-pacific-garbage-patch/

✱ ATTENDING TO EQUITY

Universal Design for Learning: Allowing students to *express* their ideas using multiple modalities of *representation* supports student ownership of their learning by giving students choice, access, and control in navigating their own understanding around the science ideas.

7 · CONTINUE SECOND RESEARCH CYCLE

15 min

MATERIALS: science notebook, *Obtaining Information Tool*, chart paper, chart paper markers, *Evaluating Sources of Information Tool*, *Evaluating Online Sources Overview*

Continue the second research cycle. Continue to display **slide L.** With the time left in the class, allow students to continue their research. Encourage students to start planning and constructing their posters.

At the end of the class, collect *Evaluating Sources of Information Tool* and *Obtaining Information Tool* to formatively assess students' progress and provide written feedback. You may also wish to provide feedback on poster progress if students have started their posters.

ASSESSMENT OPPORTUNITY	**What to look/listen for:** • Look for students to use the checklist for multiple resources and only seek to gather information once they have decided a source is credible. (SEP: 8.2, 8.3) • Look for students to record ideas from multiple sources they deem credible that are relevant to the question of what causes stars (including our Sun) to remain stable or become unstable and change. (SEP: 8.2, 8.3; DCI: ESS1.A.1, ESS1.A.4) • Students start to gather information about feedback loops (although they may not use the term) within stars between pressure out from fusion and gravity to maintain stability. (SEP: 8.3; CCC: 7.1, 7.3; DCI: ESS1.A.4) • Students start to gather information about the types of elements that stars can fuse while still remaining stable. (SEP: 8.3; CCC: 7.1; DCI: ESS1.A.4) • Students start to gather information about what happens when stars run out of elements they can fuse (burn out) or fuse iron. (SEP: 8.3; CCC: 7.1; DCI: ESS1.A.1, PS1.C.1) **What to do:** If students used sources that have questionable credibility, consider evaluating a few of the sources as a class to model what can help students identify non-credible sources using the tools. If students are struggling with gathering information from sources, model some note taking at the beginning of the next class or form a study group to practice together before having students continue independent research. If students seem to be going off on a tangent into other science ideas, remind them of our goals of figuring out what makes stars stable or unstable or suggesting they look specifically at ideas around stars running out of fuel. If students have started their posters, provide feedback using sticky notes so students can make revisions as they finish the posters. **Building Toward 4.B.1** Gather, read, evaluate, and integrate information from multiple authoritative internet sources, assessing the evidence and usefulness of each source in answering our questions about how stars (including our Sun) remain stable and can become unstable over their life cycles, and communicate the information with graphics and text. (SEP: 8.2, 8.3, 8.5; CCC: 7.1, 7.3; DCI: ESS1.A.1, ESS1.A.4, PS1.C.1)

End of day 2

8 · FINISH THE SECOND RESEARCH CYCLE

10 min

MATERIALS: *Obtaining Information Tool*, research posters started the previous day, chart paper markers, *Evaluating Sources of Information Tool*, *Evaluating Online Sources Overview*

Give students a few minutes to finish their posters. Return *Evaluating Sources of Information Tool* and *Obtaining Information Tool* to students and give them a few minutes to review the feedback. Present **slide M**. Emphasize that they must complete their posters in order for the class to share. Move around the classroom and support partner pairs who are short on time.

ALTERNATE ACTIVITY	If you have additional time, consider having students provide feedback on another group's poster and then giving students time to revise their posters before the gallery tour.

9 · GALLERY TOUR

15 min

MATERIALS: science notebook, completed research posters, tape

Conduct a gallery tour. Hang all the posters around the room or in the hallway. Present **slide N**. Encourage students to keep track of ideas in their notebooks as they tour that will help us make progress on our question about stars running out of fuel. Provide students with instructions on how they should move from poster to poster to avoid congestion.

During the gallery tour, quickly observe the posters and take note of which ones might be helpful to point to during the Consensus Discussion in order to cover all the key ideas. Remember that students may cover additional information that is not directly within the key ideas as well.

10 · COME TO CONSENSUS ON WHAT WE FIGURED OUT

15 min

MATERIALS: science notebook, chart paper, chart paper markers, stable star model from day 1

Come to consensus in a Scientists Circle. Present **slide O.** Ask students to form a Scientists Circle and bring their notebooks and a pencil. ✱ Ask the students to take charge of the discussion considering the questions on the slide through M-E-F lenses. Ask them to record their consensus ideas on chart paper as a team.

Suggested prompt	Sample student response
What processes cause stars to remain stable?	Stars are stable when they have fusion that releases energy. The equilibrium between gravity and fusion pressure that we modeled earlier continues to keep the star stable. A fluctuation or feedback between pressure from fusion and forces in by gravity keep things balanced.
What causes a star to become unstable or change?	The star running out of fuel causes it to become unstable. Stars become unstable when fusion no longer provides energy to push out against gravity. The equilibrium between gravity and fusion pressure that we modeled earlier breaks.
Does the same thing happen to every star?	No, more massive stars will be able to fuse heavier elements, but stars like the Sun will puff up and fade away. The most massive stars will not be able to maintain balance and will collapse and bounce back, causing a supernova.

If students are struggling to hit all the key ideas, use guiding questions or point to individual posters for ideas that haven't been covered yet.

✱ STRATEGIES FOR THIS CONSENSUS DISCUSSION

The following prompts can support the equitable participation for the discussion:
- Do we all agree with that?
- Who else found a similar idea to this group?
- Can someone restate in their own words what _______ just shared?

KEY IDEAS	Purpose of discussion: To establish consensus around how stars die and how the fate of a star depends on its mass. Listen for these ideas: • Stable stars exist because there is a balance (or equilibrium) between gravity forces pushing inward and the outward pushing forces of the hot, fast-moving particles at the center of the star (due to fusion). • Stars will eventually run out of hydrogen in their cores. This causes the star to condense and if the star is massive enough, creates enough concentration of particles colliding together to fuse some other elements. • Once the star no longer has enough gravity to keep fusing heavier elements, the equilibrium is broken, and the star will die. • What happens to a star when it dies depends on its mass. More massive stars run out of fuel faster, and the particle concentration is higher in the core, so they can fuse heavier elements. • When a star like the Sun runs out of hydrogen to produce energy, the core will cool and condense. The Sun will burn out/die and become a red giant because of a complicated process kicked off by this cooling and condensing and eventually fade away. • Stars with way more mass than our Sun stars can fuse elements up to iron. The fusion of iron absorbs energy instead of releasing it. • Once a star begins fusing iron, there will not be enough outward force to balance gravity, and the feedback loop that keeps the star in equilibrium will not be able to function. The result of unbalanced forces due to a star fusing iron in its core is catastrophic and results in a supernova explosion.

ADDITIONAL GUIDANCE	The connection between supernovae and guest stars may or may not have been brought up by students within their research. If this connection has not been made by students, take a moment within this discussion to tell students that what we see as guest stars is the supernova that occurs as a super-massive star dies.

Introduce the term *feedback*. If students use the term *feedback*, highlight this and ask them more about what they mean. If they do not, pick a time when they are discussing the balancing back and forth between gravity forces in and pressure forces out from fusion to introduce the term. Say, *Scientists have a term for how systems are kept in equilibrium through changes that cause other changes in the system that keep it in a balanced state. They call it a feedback loop.* Deeper understanding of this term within stellar processes will be part of the next lesson.

Compare ideas to the class model of a stable star. Once the students have come to a consensus on the key ideas listed above, ask them to look back at the class model of a stable star from the previous class and reflect on how their understanding has changed based on their research.

11 · KEEP TRACK OF OUR IDEAS AND NAVIGATE

5 min

MATERIALS: science notebook, *Progress Tracker*, paper for exit tickets

Add new words to Personal Glossaries. Display **slide P.** Ask students if there are words they should add to their Personal Glossaries. Have them discuss with an elbow partner who they did not work with today. They may want to add *supernova, equilibrium, feedback loop*, or any other words they encountered in their research and found to be unfamiliar.

Remind students of the question they wanted to answer. Have a student read the question on the bottom of the slide aloud.

- *What causes stars to remain stable or become unstable and change?*

Record ideas in Progress Trackers. Ask students if they have made progress on answering the question. Have them take out *Progress Tracker*. Ask them to record what they have figured out in their Progress Trackers. Encourage them to use any combination of words, drawings, or symbols. Ideas they may record include any of the ideas in the key ideas callout above.

Complete an exit ticket about evaluating resources. Present **slide Q**. Pose the prompts on the slide as an exit ticket:
When gathering information about stars and guest stars:
- *What resources did you find most useful in your research?*
- *What made them useful?*
- *How might you find more resources like those?*

Collect the exit tickets. Forecast that we will put the pieces together next time to see if we can model and explain the guest stars.

If you haven't already, collect the posters from around the room for review.

ASSESSMENT OPPORTUNITY	**What to look/listen for:** Look for students' posters to show: • Communication of scientific ideas about the stability and change within star systems in both graphics and text. (SEP: 8.5; CCC: 7.1, 7.3; DCI: ESS1.A.1) • Integration of the ideas they have gathered from across multiple sources to answer questions about stars' stability and change. (SEP: 8.2, 8.3; CCC: 7.1, 7.3; DCI: ESS1.A.1) • A balance (feedback loop, although they may not use the term) between gravity and pressure from fusion keeps stars stable. (CCC: 7.1, 7.3; DCI: ESS1.A.1, ESS1.A.4) • When fuel runs out for fusion, the balance (feedback loop) is broken and the star is not stable. (CCC: 7.1, 7.3; DCI: ESS1.A.1, ESS1.A.4) • When a star is unstable, it might puff outward (like our Sun will) or even explode if it is massive enough to fuse heavier elements. (CCC: 7.1; DCI: ESS1.A.1, ESS1.A.4) • Stars (with possible connections to our Sun) changing and eventually burning out. (DCI: ESS1.A.1) • Ideas about fusion of elements up to and including iron being fused in massive stars and releasing energy. (DCI: ESS1.A.4) • When a star fuses iron, the reaction absorbs energy, causing the outward pressure to disappear, causing a catastrophic event called a supernova. (DCI: PS1.C.1) Look for student exit ticket responses to show: • Ideas about what makes some resources more useful for answering scientific questions about stability and change of stars. (SEP: 8.2, 8.3; CCC: 7.1, 7.3; DCI: ESS1.A.1) • Ideas about gathering more useful sources. (SEP: 8.2, 8.3) **What to do:** If the class is having trouble integrating ideas from the online sources, spend a little bit more time doing research and working together to piece together the big ideas before putting the pieces together to model guest stars in Lesson 5. Consider pulling some examples from resources that students found to model the process of finding information, taking notes, and integrating across multiple sources. Students will engage in one more research cycle in Lesson 6. Use this opportunity to make note of students that may need additional support to fully engage in obtaining, evaluating, and communicating information. Consider how you can support students during the research cycle in Lesson 6. This may look like walking through one of the research tools with a small group again or going over some key ideas with the class. Take note of how students are communicating information within their posters. Assessment of this should be formative in this lesson, as supports have not been provided for communicating information yet. Use this opportunity to assess what students will need extra support on when this is the focus of Lesson 6. Refer to *Planning for Communicating Information Tool* and *Presentation Rubric* in the Lesson 6 materials to fully understand what the future expectations will be. Provide proactive feedback on students' posters and be explicit that this feedback is meant to help them in Lesson 6. **Building Toward 4.B.2** Gather, read, evaluate, and integrate information from multiple authoritative internet sources, assessing the evidence and usefulness of each source in answering our questions about how stars (including our Sun) remain stable and can become unstable over their life cycles and communicate the information with graphics and text. (SEP: 8.2, 8.3, 8.5; CCC: 7.1, 7.3; DCI: ESS1.A.1, ESS1.A.4, PS1.C.1)

Additional Lesson 4 Teacher Guidance

SUPPORTING STUDENTS IN MAKING CONNECTIONS IN ELA	**CCSS.ELA-LITERACY.RI.11-12.7** Integrate and evaluate multiple sources of information presented in different media or formats (e.g., visually, quantitatively) as well as in words in order to address a question or solve a problem. Students gather and evaluate sources of information from online media. The sources of information in different formats have to be integrated in order to address the research questions. **CCSS.ELA-LITERACY.RST.9-10.2**: Determine the central ideas or conclusions of a text; trace the text's explanation or depiction of a complex process, phenomenon, or concept; provide an accurate summary of thetext. Students summarize the ideas from their research and consider their application to answering the research questions on their posters for the gallery tour. **CCSS.ELA-LITERACY.SL.9-10.4** Present information, findings, and supporting evidence clearly, concisely, and logically so that listeners can follow the line of reasoning and the organization, development, substance, and style are appropriate to purpose, audience, and task. Students present their findings clearly on a poster during the gallery tour.

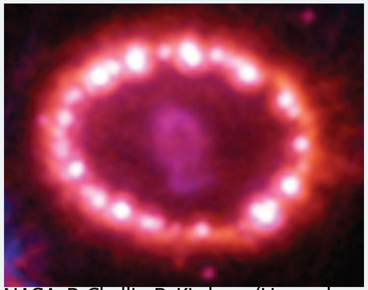
LESSON 5: Why do some stars seem unchanging, while others appear briefly, change dramatically, and fade away?

PREVIOUS LESSON *We modeled the macro forces of a star to make sense of the balance between gravity and outward pressure in stable stars. We developed research questions and were introduced to a new tool for evaluating sources. We gathered information and communicated our findings in a gallery tour. We came to consensus on what causes stars to remain stable or become unstable and change and record those ideas in our Progress Trackers.*

THIS LESSON

PUTTING PIECES TOGETHER

2 days



NASA, P. Challis, R. Kirshner (Harvard-Smithsonian Center for Astrophysics) and B. Sugerman (STScI)

We think we are ready to explain why a guest star appears and disappears, so we create a Gotta-Have-It Checklist to explain what cause-effect relationships occur within stars. We individually, then collectively, model the feedback loop that keeps stars stable and what happens when this loop is disrupted. We update the Scale Chart and revisit the DQB. We begin to wonder where the stuff for the first stars came from.

NEXT LESSON *We will look at spectra of stars, galaxies, and empty space and notice puzzling patterns in each that might hold clues to how the matter in the Universe has changed over time. We will be introduced to the Communicating Information Planning Tool and use all four research tools in small groups to obtain, evaluate, and communicate our ideas. We will come to a consensus about the evidence we uncovered, which points to an event called the Big Bang, and read about what it means that people call the Big Bang a "theory."*

BUILDING TOWARD NGSS

HS-ESS1-1, HS-ESS1-2, HS-ESS1-3, HS-PS1-8

WHAT STUDENTS WILL DO

5.A Develop and revise models based on evidence from a variety of sources to illustrate how feedback loops keep stellar systems stable and how, depending on the mass of the star, disruptions in these loops can cause sudden, catastrophic changes.(SEP: 2.3; CCC: 3.1, 7.1, 7.3; DCI: ESS1.A.4, ESS1.A.1)

WHAT STUDENTS WILL FIGURE OUT

- A guest star is a star that tried to fuse iron in its core, which is an endothermic reaction (it needs energy). This breaks the feedback loop that keeps stars stable.
- The stable period for a star ranges from a few million years for the most massive to trillions of years for the least massive.
- When the feedback loop is broken for a super-massive star, the star will collapse and bounce back out. releasing a lot of energy and fusing elements heavier than iron. When this happens, the star in the sky appears very bright.
- After this event, the energy will move outward into space, and the star will fade away as the gas begins to disperse into a remnant cloud of heavier elements.

Lesson 5 • Learning Plan Snapshot

Part	Duration		Summary	Slide	Materials
1	5 min		**NAVIGATE** Connect to related phenomena identified in Lesson 1 to begin considering cause-effect relationships that can build feedback loops.	A	Related Phenomena poster from Lesson 1
2	20 min		**DEVELOP A GOTTA-HAVE-IT CHECKLIST** Develop a Gotta-Have-It Checklist of causes and effects happening with stars that keep them stable and destabilize them. Optionally read about stellar life cycles to wrap up ideas.	B-G	*Progress Tracker*, *Stellar LifeCycle-V2* or *Stellar Life Cycle-V1* (optional), Prepared Gotta-Have-It Checklist, models, and consensus posters from Lessons 3 and 4
3	20 min		**INDIVIDUAL MODELING AND PEER FEEDBACK** Individually model the feedback loop that keeps stars stable and what disrupts these loops to cause other stars to appear briefly, change dramatically and fade away. Provide and receive peer feedback. Revise models and consider the significance of scale and quantity.	H-J	*Feedback Loop Modeling*, Gotta-Have-It Checklist
					End of day 1
4	15 min		**CONSENSUS MODELING** Develop a class consensus model and use the model to answer questions about the star systems we have been investigating.	K-L	*Feedback Loop Modeling*, Gotta-Have-It Checklist, chart paper, chart paper markers
5	7 min		**UPDATE THE SCALE CHART** Update the Scale Chart to capture how mass affects the lifecycle of a star.	M	Scale Chart poster updated in Lesson 3, sticky notes, permanent marker
6	10 min		**DQB REVISIT** Use *DQB Questions* to determine what questions from the DQB we can now answer.	N-P	*DQB Questions*, sticky notes, permanent marker, DQB
7	13 min		**ASSESSMENT EXIT TICKET** Complete the Lesson 5 Electronic Exit Ticket.	Q	Lesson 5 Electronic Exit Ticket
					End of day 2

Lesson 5 • Materials List

	per student	per group	per class
Lesson materials	• science notebook • *Progress Tracker* • *Stellar LifeCycle-V2* or *Stellar Life Cycle-V1* (optional) • *Feedback Loop Modeling* • *DQB Questions* • sticky notes • permanent marker • Lesson 5 Electronic Exit Ticket		• Related Phenomena poster from Lesson 1 • Prepared Gotta-Have-It Checklist • models • and consensus posters from Lessons 3 and 4 • Gotta-Have-It Checklist • chart paper • chart paper markers • Scale Chart poster updated in Lesson 3 • sticky notes • permanent marker • DQB

Materials preparation (15 minutes)

Review teacher guide, slides, and teacher references or keys (if applicable).

Make copies of handouts and ensure sufficient copies of student references, readings, and procedures are available.

Make copies of the handout for this lesson:
- *Stellar Life Cycle-V1* or *Stellar LifeCycle-V2* (1 per student), optional, see alternate callout below for reading level information
- *Feedback Loop Modeling* (1 per student)
- *DQB Questions* (1 per student), see preparation comment below

Three-hole-punch all handouts so they can be added to students' notebooks.

For Day 1:
- Have the Related Phenomena poster from Lesson 1 and models and consensus posters from Lessons 3 and 4 visible to the class.
- Review the Related Phenomena poster from Lesson 1 and prepare a couple of basic example feedback loops from the ideas on the poster in case students struggle with making these connections.
- Create a space for a class copy of the *Gotta-Have-It Checklist* using chart paper, projected paper, or a whiteboard. If using a whiteboard is preferred, make sure that this checklist is created in a space that can stay up for each day of the lesson and can be created and revised for each of your different class period(s).

For Day 2:
- Have a blank piece of chart paper ready to create the class consensus model.
- Have the Scale Chart poster updated in Lesson 3 visible to the class.
- Fill in *DQB Questions* with the questions from the Driving Question Board. Add new rows as needed.
- Before class, make a copy of the Electronic Exit Ticket at https://docs.google.com/forms/d/1dippcQciRvjNM6pWdC-XAywycFym6kwievoQ713w9jM/copy. Share the link to the **copy** with students, **not** the link provided here; if you share the original link, that will create a new copy for each student, and you will not have access to their responses. See the reference *Electronic Exit Tickets*.

Lesson 5 • Where We Are Going and NOT Going

This lesson was designed to coherently build toward the following disciplinary core idea elements:

- **ESS1.A.4** ~~Other than the hydrogen and helium formed at the time of the Big Bang~~, nuclear fusion within stars produces all atomic nuclei lighter than and including iron, and the process releases electromagnetic energy. Heavier elements are produced when certain massive stars achieve a supernova stage and explode. (HS-ESS1- 2),(HS-ESS1-3)

This lesson wraps up the coverage of the fusion of elements within stars with modeling it within feedback loop models. This builds on the ideas established in Lessons 2-4. The creation of hydrogen and helium in the Big Bang will be covered in Lesson 6.

- **ESS1.A.1** The star called the Sun is changing and will burn out over a lifespan of approximately 10 billion years. (HS-ESS1-1)

This lesson revisits the idea that the Sun's lifespan is approximately 10 billion years, which should have been established in Lesson 3. Students also model life cycles of stars, including ones of similar mass to the Sun and what will happen when they run out of fuel.

This lesson was designed to coherently build toward the following science and engineering practice:

- **2.3** Develop, revise, and/or use a model based on evidence to illustrate and/or predict the relationships between systems or between components of a system.

Students will independently model stability and change within star systems and then provide peer feedback before revising their models and then building a consensus model as a class.

This lesson is designed to coherently build on ideas related to the following crosscutting concepts:

- **3.1** The significance of a phenomenon is dependent on the scale, proportion, and quantity at which it occurs.

This lesson continues students' use of this concept from Lesson 3 to include both the previously established significance of atomic-scale processes driving stellar-scale stability and the significance of star mass in what happens at the end of a star's life. This element will be visited again in the Transfer Task in Lesson 7.

- **7.1** Much of science deals with constructing explanations of how things change and how they remain stable.

Building on the development of this element throughout the unit, students navigate into this lesson by making connections to other phenomena that science can help explain through the lens of stability and change. Then they model the stability and change of star systems over their lives. This element will be assessed in the Transfer Task in Lesson 7.

- **7.3** Feedback (negative or positive) can stabilize or destabilize a system.

Introduced in Lesson 4, the concept of feedback loops is the anchor for this lesson. Students will be modeling the feedback loops that keep stars stable and what happens when these feedback loops are disrupted.

In Lesson 5, students may begin to establish understanding around words that they have encountered in earlier lessons but have not had time to co-construct meaning around until now, such as: *supernova, equilibrium*, *hydrogen, remnant, exothermic, endothermic, feedback loop.* **Do not** post any words or ask students to add them to their Personal Glossaries until after the class has developed a shared understanding of their meaning.

LEARNING PLAN for LESSON 5

1 · NAVIGATE

5 min

MATERIALS: Related Phenomena poster from Lesson 1

Make connections to feedback loops in Related Phenomena. Display **slide A** and be sure the Related Phenomena poster from Lesson 1 is visible to all students. Paraphrase the text at the top of the slide: *We figured out that stars remain stable because of a cycle of cause and effect called a "feedback loop." When something happens to break that cycle, it can affect the balance of forces in the star and cause it to change.*

Then say, *Much of science looks at how systems remain stable or change. At the beginning of this unit, we thought of some other systems that seem stable over longer periods of time and then change quickly. Let's look back at those for a moment.* Then have students turn and talk about the prompts on the slide:
Choose a system that you think may have a cause and effect cycle that keeps it stable. Tell students that the system can be from the poster, or it can be another system from their experience or from a prior unit or science class.

- *Describe the cause and effect cycle that keeps that system stable.*
- *How could that cycle be disrupted and cause the system to suddenly change?*

Give students a few minutes to discuss, then have a few pairs share. Look for students to make connections between cause and effect cycles or steps that keep systems stable and how those can be disrupted to destabilize a system. It is okay if students can't cleanly explain the related phenomena feedback loops. The point is to build a connection with the concept of feedback within more relatable systems and begin to think about cause and effect relationships that connect to one another in a loop.

ALTERNATE ACTIVITY

If students are struggling with thinking about feedback loops in the things listed on the Related Phenomena poster, consider going through the following example as a class.

A system that seemed to be stable and then changed very quickly: It appears that our bodies maintain an internal temperature of around 98.6 degrees Fahrenheit, although individual variations may result in slight differences. But when we exercise or go into a hot room, our body temperature will rise. This triggers nerves in our body that activate sweat glands. The sweat will evaporate from your skin and bring your body temperature back down. This cycle will be disrupted if we do not have enough water in our system to sweat on a hot day. If this happens, your body temperature may go up by several degrees, and you could experience heat stroke, a potentially fatal change in your body system.

2 · DEVELOP A GOTTA-HAVE-IT CHECKLIST

20 min

MATERIALS: science notebook, *Progress Tracker*, *Stellar LifeCycle-V2* or *Stellar Life Cycle-V1* (optional), Prepared Gotta-Have-It Checklist, models, and consensus posters from Lessons 3 and 4

Brainstorm components. Distribute *Gotta-Have-It Checklist* to each student. Create a class version of this table either on the whiteboard, chart paper, or projected paper. Display **slide B.** Pose the task on the slide: *What are some of the* ***components*** *of star systems that we might need to explain what is happening when a star is stable and when a guest star appears and disappears?*

Point to the displayed posters from models made throughout the unit and ask students to get out their *Progress Tracker* and any other materials they think will be helpful.

Look for ideas such as:

- Star core and star outside
- Atoms (hydrogen, helium, heavier elements, iron)

- Energy
- Gravitational fields

Brainstorm interactions. Present **slide C**. Read the first prompt on the slide: *What are some of the interactions between or within these components that we might need to explain what is happening when a star is stable and when a guest star appears and disappears?*

Elicit ideas about some of the processes. Encourage students to look at our models so far. Student responses may look like:

- Fusion changing matter
- Gravity forces pulling in on matter
- Lots of energy being released and transferred
- Pressure forces pushing outward on matter
- The collapse and explosion of a supernova

If students are stumped thinking about interactions, ask them to think about processes or events. This may help them think about things like running out of fuel or fusion if they don't think about those things as interactions right now.

Ask students which column each thing should go under, causes or effects. If there is controversy about something, stir this up and suggest putting something in both columns. Record student ideas on the class version of the Gotta-Have-It Checklist.

ADDITIONAL GUIDANCE	If students need additional support in identifying causes and effects, consider using the M-E-F triangle to support students, asking them where they have seen changes in matter, transfer of energy, and balanced or unbalanced forces.

After a small collection of things has been added to the list, pose the prompt at the bottom of the slide: *What cause and effect relationships can we identify between these interactions?* Add, *In other words, do any of these interactions cause another one of these interactions to happen, and if so, how?*
Ask for one or two ideas. When a connection is suggested, draw an arrow from the cause to the effect showing directionality. Stop after only a couple of examples with the class. Highlight that things may appear multiple times on the list, connect to multiple other things, or have more than two steps in a relationship. Say, *This is a great start. Let's work with partners to fill in more details.*

Identify cause-effect relationships with partners. Display **slide D.** Say, *Working with your partner, you will go through your science notebook, Progress Tracker, class models, and handouts to continue filling in causes and effects on the Gotta-Have-It Checklist and making connections between them.*

After students have made progress but seem to be slowing down, pause and call on a few pairs to share their ideas. Listen for students to summarize one or more of the key ideas represented in the example Gotta-Have-It Checklist in the Key Ideas callout below. Ask students to copy new ideas they hear from their peers into their checklists as you scribe them at the front of the room.

Come to a consensus on the Gotta-Have-It Checklist as a class. Present **slide E**. Ask students what cause and effect pairs we need to add to (or remove from) our Gotta-Have-It Checklist so that we can make a model to explain: *Why do some stars seem stable, while others appear briefly, change dramatically, and fade away?* Make sure that some version of the following ideas are represented somewhere in the checklist:

KEY IDEAS	• **Forces** from gravity create extreme heat and pressure in the core of a star → hydrogen atoms move fast enough **to overcome electric repulsion forces** when they collide, **fusing** them into helium. • Fusion of hydrogen **releases electromagnetic energy**, which heats up matter in the core of a star → the core of the star expands. • When the **matter** in the core of the star expands too much → pressure on the matter goes down and fusion slows down a bit. • When the **matter** in the core of the star is not expanding enough to balance gravity → pressure on the matter goes up, and fusion speeds up. • **Gravity forces** pulling matter inward and the **forces from the expanding matter** in the core due to fusion pushing outward become balanced → this feedback loop keeps the **forces in the star** balanced so that they **appear not to change**, and the star remains stable. • A star runs out of **hydrogen** → if the star has **enough mass**, gravity pushes in on the core, and **heavier elements are fused**, up to iron. • A star runs out of fuel (**matter**) because the gravity from its mass can no longer provide enough heat to fuse the elements left in the core → it becomes **unstable and dies** because the **forces** are out of balance. • A star that is not massive enough to fuse iron, like our Sun, dies → it becomes a red giant/white dwarf and fades away because **electric forces** between particles will balance gravity. • A star is **massive enough** that gravity can cause enough heat and pressure to fuse iron → **energy is absorbed by the fusion of iron** and the outward pressure disappears → the star collapses and then explodes, which is called a **supernova**; this **releases lots of energy and fuses elements heavier than iron**. • A star that was too dim to see with our eyes from Earth dies in a supernova → the **supernova** is super **bright** and makes the star visible with our eyes but then fades away in a few months (a guest star). • A supernova **fades** as energy moves away → a collapsed core and **remnant** cloud are left behind.

ALTERNATE ACTIVITY	If students have not brought up all the big ideas so far or need extra support, use *Stellar LifeCycle-V2* or *Stellar Life Cycle-V1* to provide a recap and review before moving on to modeling. *Stellar LifeCycle-V2* is written at a high school level and *Stellar Life Cycle-V1* is written at the level of a student entering middle school. Consider providing one of these readings to individual students or incorporating it into the lesson as a class activity. Then return to the Gotta-Have-It Checklist to fill in missing ideas. **Slide F** can be used to structure annotating the reading. As students read, they should underline ideas that they see from their Gotta-Have-It Checklist and circle ideas that they think they should add because they will help us explain how guest stars can appear suddenly and then disappear while other stars remain stable.

Turn and Talk to make sure we have everything. Present **slide G**. Ask students to turn and talk with a partner about the prompt on the slide: *Do we have ideas represented on our checklist that help explain:*

- *Matter changes*
- *Energy transfer*
- *The effect of forces being balanced or unbalanced*
- *How stars remain stable*
- *How stars change suddenly*

Call on one pair per bullet and ask them to identify an idea on the checklist corresponding to that bullet. If the class cannot identify an idea, give students some time to go back to the reading and their Progress Trackers and identify an idea to fill in the gaps.

ADDITIONAL GUIDANCE	Take a moment to discuss the ambiguity of language associated with events in astronomy. Many terms, such as "supernova explosion" referring to a process of implosion and explosion, were established before the current understanding of the phenomenon was developed. Another example is the "planetary nebula" left after a red giant dissipates. This term sounds like it contains or creates planets, but a planetary nebula is not related to planets. This term was used because these nebulae appeared round like a planet in a telescope, especially compared to other distant astronomical objects, which appear either diffuse or pointlike. Highlight how scientific understanding changes and advances over time and how our terminology often reflects the history of science as a human endeavor. A non-astronomy example is how current is modeled as the flow of positive charges through a wire. We now know it is the negatively charged electrons that move, yet we still model the current in the opposite direction. There is also ambiguity inherent in the term supernova. If you search "supernova," the images that appear are typically *remnants* of supernovae, not of supernovae. What is the difference? Astronomers agree that SN 1987a is now a remnant. Around the year 2000, 13 years after the initial implosion and resulting explosion, the energy we observed from the shockwave colliding with surrounding gas became stronger than the energy from the explosion itself. This change marked the transition from supernova to supernova remnant. Much like the distinction between a planet vs. a dwarf planet or a meteorite vs. a meteoroid, these terms are useful only in that they help scientists classify objects into categories. It is not important to enforce this vocabulary in the classroom as students develop intuitive mechanistic understandings of the Universe.

3 · INDIVIDUAL MODELING AND PEER FEEDBACK

20 min

MATERIALS: science notebook, *Feedback Loop Modeling*, Gotta-Have-It Checklist

Model individually. Present **slide H** and distribute *Feedback Loop Modeling*. Ask students to develop a series of models to tell the feedback loop story of what keeps some star systems stable and what happens that causes others to change dramatically. Encourage students to use any combination of drawings, words, and symbols. Remind students that if they change scale, they should use symbols or words to indicate this change in scale.

Provide peer feedback. Present **slide I**. Ask students to take turns sharing their models with a partner and providing feedback. Suggest that they use the Gotta-Have-It Checklist as a tool for reviewing their models. Reinforce for students that science is a collaborative endeavor and sharing ideas is not cheating because it helps us all move our thinking forward.

Give students a few minutes to make revisions to their models based on peer review. Then present **slide J** and ask students to answer the two prompts on *Feedback Loop Modeling*.

- *Describe how scale is significant within the feedback loop of stable stars you modeled above.*
- *Describe what quantity is significant in determining what happens to a star at the end of its life. What will happen to our Sun at the end of its life?*

Collect *Feedback Loop Modeling* to provide written feedback before the next class.

ASSESSMENT OPPORTUNITY	**What to look/listen for in the moment:** • Students using words and/or pictures to represent the feedback cycle that keeps star systems stable during most of their lifetimes. (SEP: 2.3; CCC: 7.3; DCI: ESS1.A.4, ESS1.A.1) • Students are modeling interactions between components of a star system at more than one moment in time to show stability and change over a stellar lifetime. (SEP: 2.3; CCC: 7.1; DCI: ESS1.A.4, ESS1.A.1) • Students identify that scale is significant within stable stars in their models because atomic-scale fusion processes within the core (one part of the star system) drive stellar-scale forces to keep the star in equilibrium. (SEP: 2.3; CCC: 3.1, 7.1, 7; DCI: ESS1.A.4, ESS1.A.1) • Students identify that the quantity of mass that a star has is significant to what happens at the end of its life because the mass of a star determines if it will be able to fuse iron or not, therefore determining if it will become a supernova and identifying that our Sun doesn't have enough mass to become a supernova and will burn out and become a red giant. (CCC: 3.1; DCI: ESS1.A.4, ESS1.A.1) • Student models illustrate fusing of elements lighter than iron (mostly hydrogen into helium) in stable stars and the fusion of iron disrupting the feedback loop, causing massive stars to become unstable and explode in a supernova. (SEP: 2.3; CCC: 7.1, 7.3; DCI: ESS1.A.4, ESS1.A.1) • Student models illustrate elements heavier than iron being fused in supernovae and left in the remnant clouds. (SEP: 2.3; DCI: ESS1.A.4) See *Example Student Models* for example student models and suggested feedback. **What to do:** • Refer students back to the Gotta-Have-It Checklist and help students to confirm that all relevant ideas are included from their checklist on their models. • Ask students if processes are happening at different scales that might affect the star over its lifetime, and if so, what those processes are and how they can be included in their models. • Ask students if there are changes in matter, energy transfer, or forces that need to be included in their models. • Direct students back to the cause and effect connections on their Gotta-Have-It Checklist and suggest they loop for places where an effect also appears in the causes column or is connected back to another process. **Building Toward: 5.A.1** Develop and revise models based on evidence from a variety of sources to illustrate how feedback loops keep stellar systems stable and how, depending on the mass of the star, disruptions in these loops can cause sudden, catastrophic changes.(SEP: 2.3; CCC: 3.1, 7.1, 7.3; DCI: ESS1.A.4, ESS1.A.1)

End of day 1

4 · CONSENSUS MODELING

15 min

MATERIALS: science notebook, *Feedback Loop Modeling*, Gotta-Have-It Checklist, chart paper, chart paper markers

Develop a class consensus model. ✱ Return *Feedback Loop Modeling* to students and give them a couple of minutes to review your feedback. Display **slide K.** Ask students to gather in a Scientists Circle. Have students bring *Feedback Loop Modeling* and their science notebooks containing their completed Gotta-Have-It Checklists. Have students facilitate their own consensus modeling discussion, following the processes and routines established throughout the course. Have students record their consensus model on chart paper.

Check if the model answers our questions. Display **slide L.** Say, *Let's check to see if our model explains all the different types of star systems we have been considering.* Read the questions on the slide, taking time for students to consider them and answer between each prompt.

✱ ATTENDING TO EQUITY

Universal Design for Learning: Applying past ideas that were learned by exploring other investigative phenomena to new phenomena, both individually and as a class, can help students revisit key ideas over time.

- *Does our model describe what keeps most stars stable for a very long time?*
- *Does our model explain what causes guest stars to appear in the sky suddenly and then disappear?*
- *Does our model predict what will eventually happen to our Sun?*

If the model doesn't answer all the questions, direct students to add to the model.

Circle back to M-E-F. Say, *When we started, we were not sure how forces would come into play in thinking about stability in stars. It feels like we have come a long way now.*

This can help students better *represent* their ideas in a new context and create linkage between ideas.

5 · UPDATE THE SCALE CHART

7 min

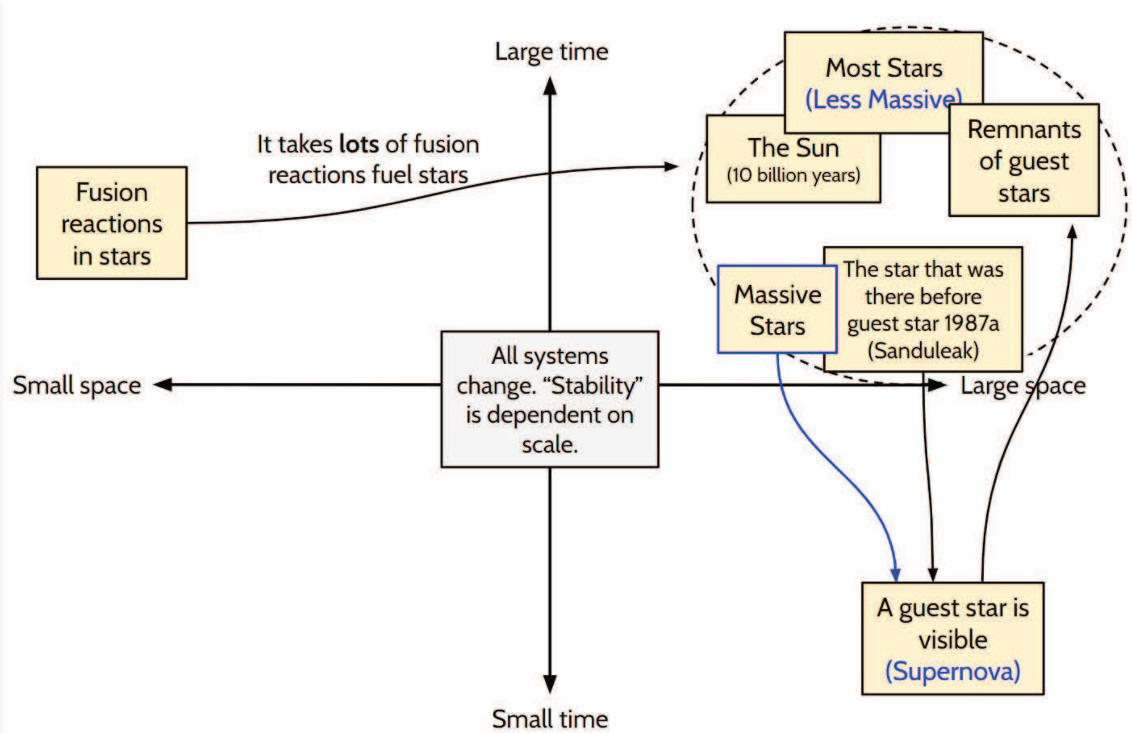
MATERIALS: Scale Chart poster updated in Lesson 3, sticky notes, permanent marker

Make scale explicit with the Scale Chart. Stay within a Scientists Circle and display **slide M**. Say, *We have put a lot of pieces together with our Gotta-Have-It Checklist and feedback loop models. Let's connect back to our Scale Chart poster and capture how not all stars are stable for the same amount of time.* Ask students the question on the slide: *What determines how long a star can remain stable?* Look for students to identify mass. If they do not, point them to the last question on *Feedback Loop Modeling*.

Ask students how this should be represented on the Scale Chart and have them update the chart once they have come to a consensus. Look for them to separate stars by mass, with more massive stars, including the star that was there before guest star 1987a (Sanduleak), lower on the time scale and less massive stars, including our Sun, higher on the time scale. Look for them also to make a connection between massive stars and when a guest star is visible. They may also add "supernova" to that sticky note for guest stars being visible.

Ask students what kind of time scales we are even considering. Look for them to acknowledge that these are super-long time scales and that even massive stars are stable for millions of years before becoming supernovae. Take this opportunity to highlight that we know our Sun will be stable for about 10 billion years (about 5 billion from now). Students may want to add a reference to a human lifetime to the scale chart as a reference between guest stars and stable stars.

Note that each class's Scale Chart will look different and they are not meant to be precise or to scale. The main idea is to identify significant differences in scale between phenomena. Students may also want to capture other things on the scale chart, such as that less massive stars become red giants. One example of what the Scale Chart may look like is shown below. Blue shows suggested additions in this lesson.



6 · DQB REVISIT

10 min

MATERIALS: *DQB Questions*, sticky notes, permanent marker, DQB

Revisit the Driving Questions. Distribute *DQB Questions* with the list of questions developed on the Driving Question Board. Have students work individually to mark questions they think the class has answered using the key on the handout and **slide N.✱**

- We did not answer this question or any parts of it yet: **X.**
- Our class answered some parts of this question, or I think I could answer some parts of this question: **✓.**
- Our class answered this question, or using the ideas we developed, I could now answer this question: **✓+.**

Look for questions about where matter comes from, the Big Bang, the origin of the Universe, or the history of the Universe and stars. Highlight these questions and draw a big circle around them. If there are no questions that relate, that is fine.

Navigate by considering matter changes in the Universe over time. Present **slide O**. Say, *We figured out that over millions or even billions of years, stars convert lighter elements like hydrogen and helium into heavier and heavier elements.*

Ask students to turn and talk about the prompt on the slide: *What effects would these matter changes we described in stars and supernovae/guest stars have on the Universe over time, and what data do we need to figure this out?*

✱ SUPPORTING STUDENTS IN ENGAGING IN CONSTRUCTING EXPLANATIONS AND DESIGNING SOLUTIONS

Students are constructing explanations for questions that they have developed thus far in the unit. Students are using valid and reliable evidence from a variety of sources, including their own models and investigations, to determine if they can construct an explanation to these questions that relate to scales of time representing events that happened in the past and those that will continue to happen in the future.

Bring the class back together and elicit 2-3 ideas. Look for ideas about how over time there would be less and less hydrogen and more and more heavy elements. Say, *Could we measure the composition of the Universe to try to figure this out?* Look for students to agree or be open to this idea.

Then present **slide P** and pose the questions on the slide.

- *How could we measure the composition of the whole Universe and how it has changed over time?*
- *What unanswered DQB questions could this line of inquiry help us address?*
- *What new questions does this bring up for you? Add any new questions to the DQB.*

Give students time to add new questions to the DQB.

7 · ASSESSMENT EXIT TICKET

13 min

MATERIALS: Lesson 5 Electronic Exit Ticket

Send students to complete the Lesson 5 Electronic Exit Ticket. Project **slide Q.** Have students complete the Electronic Exit Ticket. Use the *Electronic Exit Ticket Key for Lesson 5* to score the Exit Tickets and get a sense of which students might be struggling to put the pieces together. The key also includes targeted feedback for students who are in different places in their learning.

ASSESSMENT OPPORTUNITY	**What to look/listen for in the moment:** Use the *Electronic Exit Ticket Key for Lesson 5* to score the Exit Tickets across all three dimensions. (SEP: 2.3; CCC: 3.1; DCI: ESS1.A.4, ESS1.A.1) **What to do:** The key also includes targeted feedback for students who are in different places in their learning. **Building Toward: 5.A.2** Develop and revise models based on evidence from a variety of sources to illustrate how feedback loops keep stellar systems stable and how, depending on the mass of the star, disruptions in these loops can cause sudden, catastrophic changes.(SEP: 2.3; CCC: 3.1, 7.1, 7.3; DCI: ESS1.A.4, ESS1.A.1)

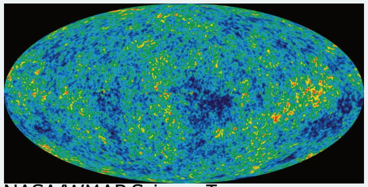
LESSON 6: How has the matter in the Universe changed over time, and how do we know?

PREVIOUS LESSON *We created a Gotta-Have-It Checklist to explain what cause-effect relationships occur within stars. We individually and collectively modeled the feedback loop that keeps stars stable and what happens when this loop is disrupted. We updated the Scale Chart and revisited the DQB. We began to wonder where the stuff for the first stars came from.*

THIS LESSON

INVESTIGATION

4 days


NASA/WMAP Science Team

We look at spectra of stars, galaxies, and empty space and notice puzzling patterns in each that might hold clues to how the matter in the Universe has changed over time. We decide to research each question and come back together to communicate our findings. We are introduced to the [material: PB.L6.HO2] and use all four research tools in small groups to obtain, evaluate, and communicate our ideas. We come to consensus about the evidence we uncovered, which points to an event called the Big Bang, and read about what it means that people call the Big Bang a "theory." Finally, we add to our Progress Trackers and our Personal Glossaries.

NEXT LESSON *We will record questions we still want answered on our DQB and then broaden to think about questions we have about other types of phenomena. We will reflect on what investigations we can through online research, future science classes, a career in STEM, and/or a lifetime of curiosity. We will then engage in a final transfer task.*

BUILDING TOWARD NGSS

HS-ESS1-1, HS-ESS1-2, HS-ESS1-3, HS-PS1-8

WHAT STUDENTS WILL DO

6.A Read, evaluate, and communicate information about the Big Bang to explain that the theory is supported by empirical evidence of spectral patterns, including observations of distant galaxies receding from our own, of the measured composition of stars and non-stellar gases, and of maps of radiation permeating the Universe. (SEP: 8.3, 8.5, 7.2; CCC: 1.5; DCI: ESS1.A.3, ESS1.A.2, ESS1.A.4)

WHAT STUDENTS WILL FIGURE OUT

- The Big Bang theory is supported by evidence.
- Evidence for the Big Bang includes observations of distant galaxies moving away from us, the measured composition of stars, and maps of spectra of the cosmic microwave background, which all match Big Bang models.

Lesson 6 • Learning Plan Snapshot

Part	Duration		Summary	Slide	Materials
1	5 min		**NAVIGATION** Use the consensus model to think about changes to the composition of the Universe. Motivate looking at spectra of stars, galaxies, and space.	A-B	Consensus model from Lesson 5, chart paper, markers
2	27 min		**LOOK AT SPECTRA OF STARS, GALAXIES, AND SPACE** Make predictions about what we will see. Look at three types of spectra: stars, galaxies, and empty space. Record three questions at the front of the room related to these spectra that will motivate research.	C-J	*Galactic Spectra*, *Star Spectra* from Lesson 2
3	13 min		**INTRODUCE THE COMMUNICATION TOOL** Review why it was important to be intentional in how we communicate scientific ideas. Introduce the communication tool.	K-L	*Planning for Communicating Information Tool*
					End of day 1
4	45 min		**THIRD RESEARCH CYCLE** Engage in a research cycle about spectra of the Universe and how they serve as evidence of the Big Bang theory.	M-N	*Planning for Obtaining Information Tool*, *Evaluating Sources of Information Tool*, *Obtaining Information Tool*, *Planning for Communicating Information Tool*
					End of day 2
5	15 min		**COMPLETE THIRD RESEARCH CYCLE** Students wrap up the third research cycle of the unit in groups.	none	*Planning for Obtaining Information Tool*, *Evaluating Sources of Information Tool*, *Obtaining Information Tool*, *Planning for Communicating Information Tool*
6	30 min		**TIMED GALLERY TOUR** Look for common mechanisms and ideas in a timed gallery tour.	O-P	
					End of day 3
7	20 min		**BUILDING UNDERSTANDINGS DISCUSSION** Hold a Building Understandings Discussion about the Big Bang. Highlight lines of evidence for the Big Bang.	Q-R	
8	20 min		**BIG BANG READING** Read about the Big Bang. Respond to the prompts in the reading to identify the three major lines of evidence supporting this theory.	S-T	*BigBang Theory V2* or *BigBang Theory V1*
9	5 min		**KEEP TRACK OF OUR IDEAS AND NAVIGATE** Add new words to Personal Glossaries. Remind students of the question they wanted to answer. Record ideas in Progress Trackers.	U	
					End of day 4

Lesson 6 • Materials List

	per student	per group	per class
Lesson materials	• *Galactic Spectra* • *Star Spectra* from Lesson 2 • *Planning for Communicating Information Tool* • *Planning for Obtaining Information Tool* • *Evaluating Sources of Information Tool* • *Obtaining Information Tool* • *BigBang Theory V2* or *BigBang Theory V1* • science notebook		• Consensus model from Lesson 5 • chart paper • markers

Materials preparation (20 minutes)

Review teacher guide, slides, and teacher references or keys (if applicable).

Make copies of handouts and ensure sufficient copies of student references, readings, and procedures are available.

Three-hole-punch all the images and handouts so they can be added to students' notebooks.

Lesson 6 • Where We Are Going and NOT Going

Where We Are Going

This lesson is designed to coherently build on ideas related to the following disciplinary core ideas:

- **ESS1.A.3** The Big Bang theory is supported by observations of distant galaxies receding from our own, of the measured composition of stars and non-stellar gases, and of the maps of spectra of the primordial radiation (cosmic microwave background) that still fills the Universe. (HS-ESS1-2)
- **ESS1.A.2** The study of stars' light spectra and brightness is used to identify ~~compositional elements of stars~~, their movements, and their distances from Earth. (HS-ESS1- 2),(HS-ESS1-3)
- **ESS1.A.4** Other than the hydrogen and helium formed at the time of the Big Bang, ~~nuclear fusion within stars produces all atomic nuclei lighter than and including iron, and the process releases electromagnetic energy. Heavier elements are produced when certain massive stars achieve a supernova stage and explode.~~ (HS-ESS1- 2),(HS-ESS1-3)

This lesson is designed to coherently build on ideas related to the following science and engineering practices:

- **8.3** Gather, read, and evaluate scientific and/or technical information from multiple authoritative sources, assessing the evidence and usefulness of each source.

Students build on their previous engagement in this element in the research cycle in Lesson 4. They are gathering new information from different sources and should be starting to rely less on the research tools as supports.

- **8.5** Communicate scientific ~~and/or technical~~ information or ideas (e.g., about phenomena ~~and/or the process of development and the design and performance of a proposed process or system~~) in multiple formats (i.e., orally, graphically, textually, mathematically).

Students build on their initial engagement in this element in Lesson 4 by reviewing feedback on their posters from that lesson and then using the *Planning for Communicating Information Tool* to plan and complete a presentation related to evidence supporting the Big Bang.

- **7.2** Evaluate the claims, evidence, and/or reasoning behind currently accepted explanations or solutions to determine the merits of arguments.

This element appears in this unit only within this lesson. It is key to students' sensemaking while evaluating evidence that supports the Big Bang theory, building off students' engagement in this element within other units and courses.

This lesson is designed to coherently build on ideas related to the following crosscutting concept:

- **1.5** Empirical evidence is needed to identify patterns.

This element builds off of students' development of understanding spectra and their role as empirical evidence about stars and galaxies that are too far away to collect other empirical data on.

This lesson also gives students the opportunity to read about and reflect on connections to the Nature of Science, including the following three elements from NGSS Appendix H:

- **Science Models, Laws, Mechanisms, and Theories Explain Natural Phenomena**: A scientific theory is a substantiated explanation of some aspect of the natural world based on a body of facts that has been repeatedly confirmed through observation and experiment, and the science community validates each theory before it is accepted. If new evidence is discovered that the theory does not accommodate, the theory is generally modified in light of this new evidence.
- **Science is a Way of Knowing**: Science knowledge has a history that includes the refinement of, and changes to, theories, ideas, and beliefs over time.
- **Science is a Human Endeavor**: Scientific knowledge is a result of human endeavor, imagination, and creativity.

Students will encounter or co-develop definitions for the following words in this lesson: *Big Bang, nucleogenesis, cosmic microwave background*, or any other words they encountered in their research and found to be unfamiliar. **Do not** post any words or ask students to add them to their Personal Glossaries until after the class has developed a shared understanding of their meaning.

Where We Are NOT Going

This unit addresses the NGSS DCIs related to the Big Bang by introducing the ideas broadly, but because students will be using different sources to obtain this information, there is no prescribed set of representations, data, or images that students will use to figure this out. For this reason, the unit does not expect students to understand or use visualizations of the cosmic microwave background, horn-shaped models of the Universe across time, or timelines of the history of the Universe. If students are particularly interested in this topic, an extension opportunity is offered at the end of the lesson.

LEARNING PLAN for LESSON 6

1 · NAVIGATION

5 min

MATERIALS: Consensus model from Lesson 5, chart paper, markers

Use the consensus model to think about changes to the composition of the Universe. Present **slide A.** Remind students about the feedback loop consensus model we made together last time, using our Gotta-Have-It Checklists. Say, *After we modeled, we were wondering: How could the matter changes we described in stars change the composition of the whole Universe over time?* Then ask, *How could we measure the composition of the whole Universe and how it has changed over time?*

Look for students to mention spectra.

ADDITIONAL GUIDANCE	If students are stumped, pose the following question to the class: *How do we measure the composition of objects in space, like a star?* Encourage students to go back into their notebooks to remind themselves about how we measured the composition of stars in Lesson 2, where we looked at spectra.

Motivate looking at spectra of stars, galaxies, and space. Present **slide B.** Have students turn and talk about the questions on the slide:

- *What might looking at a spectrum tell us about the Universe?*
- *Can we take a spectrum of the whole Universe?*
- *Which parts would need to take spectra of to make sure we are getting the whole thing?*

Give students 1-2 minutes and then elicit ideas about the last question on the slide.

Record a list of these ideas at the front of the room. Students may also come up with more specific ideas, such as planets, black holes, dust, nebulae, white dwarfs, etc. Record these ideas and then spend a moment organizing them. It may be helpful to suggest using scale to group things in order to differentiate between individual stars and remnants and whole galaxies that are much farther away.

You will need some version of the following three parts on the table:

1. Stars (and stellar remnants along with planets)
2. Galaxies (lots of stars together but really far away)
3. Empty space (between everything else)

ADDITIONAL GUIDANCE	If students don't come up with empty space, put it on the table. *What about the space between stars and galaxies? What would we see if we zoomed in there? And then zoomed in again? Should we include spectra of that empty space as well?* If students suggest taking spectra of planets in other solar systems on their own, say, *It is very difficult to take the spectra of planets around other stars, and scientists can only do it by taking the spectra of stars and then separating out the spectra of planets. So if we take the spectra of distant stars, that includes planets!* If students don't come up with galaxies as a separate category, suggest it. Point out that we can observe individual star systems within our galaxy but not within other galaxies because they are so far away.

✱ SUPPORTING STUDENTS IN DEVELOPING AND USING PATTERNS

In high school, students should engage with the idea that empirical evidence is needed to identify patterns. Take a moment to remind students that light is the primary source of empirical data we have about objects in space because they are too far away to collect matter from. Spectra represent a way to analyze this light and extract as much information from it as we can. This makes spectroscopy (the study of spectra) fundamental for identifying patterns to help us make sense of the Universe.

2 · LOOK AT SPECTRA OF STARS, GALAXIES, AND SPACE

27 min

MATERIALS: *Galactic Spectra*, *Star Spectra* from Lesson 2

Make predictions about what we will see. Present **slide C** and ask students to make predictions individually in their notebooks for the prompt on the slide:
What do you predict we will learn about the whole Universe from each of these spectra?

- *Stars*
- *Galaxies*
- *Empty space*

Prepare to look at three types of spectra. You can explore space, galaxies, and stars in whatever order makes sense to the class.

1. To explore spectra of **stars**, go to **slide D**, and read step 3) below.
2. To explore spectra of **galaxies**, go to **slide F**, and read step 2) below.
3. To explore spectra of **empty space**, go to **slide H**, and read step 1) below.

The goal of looking at these spectra is to get students asking questions that will lead them to research questions that will lead them to the Big Bang, but without front-loading this concept. Each spectra will foster questions that will lead to a line of evidence that supports the Big Bang theory and how it explains the composition of the Universe and how it changes over time.

1) SPECTRA OF STARS

Look at spectra of stars again. Present **slide D** and distribute *Star Spectra* from Lesson 2. Say, *We looked at spectra of stable stars in Lesson 2. What did we notice about the matter? Is this well explained by our models? What does that make you wonder?*
Students may notice:

- There are dark lines that show what kinds of matter the stars are made up of.
- We see mostly hydrogen and helium (even though these elements are being used up as fuel in stars).
- They range in temperature but are all pretty hot.
- Different masses/temperatures look different.

Students may wonder:

- Why are different stars made up of different things?
- Why is there so much hydrogen and helium in stars?
- Where did all the hydrogen and helium come from?
- Why does the temperature affect the spectrum like that?

Encourage students to think back to our consensus models for stars and think about what we know about stars that is not well explained by that model. If students don't pose questions about where the hydrogen and helium in stars comes from, say, *Our models explain how stars and supernovae create other elements out of hydrogen through fusion. This explains where all those elements come from, but do we have something to explain where the hydrogen and helium came from?*

Record a question on our list of questions about the matter in the Universe. If you have not already, title a new piece of chart paper "Questions about the matter in the Universe and how it changes." Use **slide E** to pose the following question: *What research question(s) could we investigate to better understand the origins of the matter that makes up stars?*

Based on the language used by students, record a focal research question that looks something like:

- Where does all the hydrogen and helium that make up stars come from?

If students have other questions, have them record them in their notebooks to consider later.

2) SPECTRA OF GALAXIES

Look at spectra of galaxies. Present **slide F**. Tell students, *When scientists take spectra of all the galaxies in the Universe, they see this.* Distribute *Galactic Spectra*. If you haven't already, distribute *Star Spectra* from Lesson 2 for comparison. Ask, *What do you notice? Is this explained by our models? What does that make you wonder?*

Students may notice:
- The line patterns seem to be similar but more squished over.
- They seem to all still be made out of mostly hydrogen and helium (which makes sense since they are made out of stars).
- The hydrogen lines are there, but they are moved over.
- The further away the galaxy, the more shifted it is.

Students may wonder:
- Why are the spectra of galaxies shifted to the right?
- What else is in a galaxy other than stars, their planets, and stellar remnants?
- Are some galaxies older than others?

Encourage students to think back to our consensus models for stars, because galaxies are made of stars, and think about what we noticed about galaxy spectra that is not well explained by that model.

ADDITIONAL GUIDANCE	If students don't notice that the lines are shifted over, cut a copy of the *Galactic Spectra* into strips. Then have students compare the lines. Ask, *What do you have to do to get the lines to match up more?*

Record a question on our list of questions about the matter in the Universe. If you have not already, title a new piece of chart paper "Questions about the matter in the Universe and how it changes." Present **slide G** and pose the question on the slide: *What research question(s) could we investigate to better understand the differences in galactic spectra?*

Based on the language used by students, record a question that looks something like:
- Why are the spectra of some galaxies shifted to the right?

3) SPECTRA OF EMPTY SPACE

Look at spectra of empty space. Present **slide H** and distribute *Empty Space Spectra*. Tell students, *When scientists measure the electromagnetic energy coming from <u>space</u>, they actually do get a spectrum, but not in the visible light. It looks like this.* Ask, *What do you notice? What do you wonder?*

Students may notice:
- There aren't dips like in the other spectra.
- It's mostly in the microwave part of the spectrum.

Students may wonder:
- How are there spectra from empty space?
- Why are there no dips?
- What is producing this radiation/light? Is it stars? Galaxies? Dust? Something else?

Identify the wavelength of this radiation. After students begin to share noticings and wonderings, ask students to think back to *OpenSciEd Unit P.5: How do we use radiation in our lives and is it safe for humans? (Microwave Unit)* and use the diagram of the electromagnetic radiation spectrum below the empty space spectra. Then ask, *How do we describe electromagnetic radiation in these wavelengths, and where else do we see this kind of radiation?*

Students should be able to identify that the spectra from empty space are closest to the microwave wavelengths.

ADDITIONAL GUIDANCE	The peak intensity of the spectra emitted by space is near 0.1 cm. Students may need help finding the equivalent wavelength on the electromagnetic spectrum. Remind them that 0.01 is equal to 10^{-1}. This should help them identify that this spectrum is in the range of microwaves.

Look at the temperature of space. Present **slide I** and direct students' attention to the last image on *Empty Space Spectra*. Say, *Scientists also collected data on the temperature of empty space. This image shows temperature differences across empty space with different colors.* Ask, *What do you notice? What do you wonder?*

Students may notice:

- The temperature of space is not the same.
- It's mostly blue and green, but there's some red.

Students may wonder:

- What makes different parts of space different temperatures?

Record a question on our list of questions about the matter in the Universe. If you have not already, title a new piece of chart paper "Questions about the matter in the Universe and how it changes." Present **slide J.** Pose the question on the slide: *What research question(s) could we investigate to better understand the presence of microwave radiation everywhere in empty space?*

Based on the language used by students, record a question that looks something like:

- "Where does this microwave radiation in empty space come from?"

You might also include a subquestion if students are curious about something else.

Motivate another research cycle. Once you have gone through all three spectra groups, point to the questions we have developed on the poster to help us understand the composition of the whole Universe and how it has changed over time. Suggest, *Let's see if we can answer these questions using our research tools.* Explain to students that they will get a chance to answer one of the questions we developed.

3 · INTRODUCE THE COMMUNICATION TOOL

13 min

MATERIALS: *Planning for Communicating Information Tool*

Review why it was important to be intentional in how we communicate scientific ideas. Present **slide K.** Tell students they can choose how they want to communicate their research, but they need to be thoughtful about how to communicate. Ask, *Why was this again?* Suggest that students think back to our conversation in Lesson 4 about the importance of communication. They should have saved their Stop and Jots from Lesson 4 in their notebooks (titled "Why is it important to be intentional in how we communicate scientific ideas?") and can look back at those now.

If you haven't already done so, return your feedback on students' Lesson 4 posters now. Otherwise, have students take it out. Give them a moment to review the feedback and think about what they can improve upon this research cycle.

Introduce the communication tool and task for the new research cycle. Distribute *Planning for Communicating Information Tool*. Say, *I have a new tool for us to help us further organize and develop our skills communicating information from our research.* Give students time to ask questions.

Display **slide L.** Read the text and prompt on the slide:
For this research cycle, your group will choose what format you want to use to communicate your findings. ✱

- *What formats might be useful for communicating your research findings?*

Have a few students share their thoughts. Look for students to offer a variety of modalities, such as a poster, 3D model, text article, or presentation. Discuss that the class will be using a gallery tour to share information and the specific constraints that come with this within your classroom.

✱ ATTENDING TO EQUITY

Universal Design for Learning: Allowing students to choose in which formats they will communicate their research findings not only helps them learn about various ways in which information can be communicated but also allows students to *express* their findings in modalities most accessible and *engaging* for them.

ALTERNATE ACTIVITY	One constraint on these presentation formats is that there will be a gallery tour, so if groups want to do an oral presentation, for example, they will need to make a recording and set it up on a laptop, and it should be no more than 4 minutes long. Posters, 3-D models, articles, all are welcome. Other options for the teacher to use in place of the gallery tour or for the teacher to offer as options to students are: a curated gallery tour, a series of presentations, presentations in front of a larger, community audience, or groups making a video presentation.

Prepare for the next research cycle. Break students into new small research groups to begin to discuss what question they will investigate and their ideas about how they want to communicate their findings.

Before the end of class, pass out new fresh copies of *Planning for Obtaining Information Tool*, and *Obtaining Information Tool*.

ADDITIONAL GUIDANCE	Keep in mind that it will be important to have some students working on each of the questions developed by the class so that we get all three lines of evidence on the table. If for some reason this does not happen, all three lines of evidence are reviewed in the reading, but ideally at least one group will be researching the cosmic microwave background, at least one group will be researching the shift in galactic spectra toward the red, and at least one group will be researching the abundances of hydrogen and helium in stars.

End of day 1

4 · THIRD RESEARCH CYCLE

45 min

MATERIALS: *Planning for Obtaining Information Tool*, *Evaluating Sources of Information Tool*, *Obtaining Information Tool*, *Planning for Communicating Information Tool*

Reflect on learning so far. Display **slide M.** Say, *We have already engaged in multiple research cycles and have learned a lot about how to obtain, evaluate, and communicate information. Let's take a moment to reflect on our learning so far.* Have students turn and talk about the prompts on the slide:

- *In the past research cycles, what did you feel were your strengths in obtaining, evaluating, and communicating information?*
- *What skills would you like to focus on improving this cycle?*

Give students time to work in their groups. Present **slide N**. Provide the entire class for students to work on their research and presentation using *Planning for Obtaining Information Tool*, *Evaluating Sources of Information Tool*, *Obtaining Information Tool*, and *Planning for Communicating Information Tool*. Remind students that these are intended to be tools for them but that you will not be grading on how complete these tools are. Consider telling students for whom these tools might feel elementary that if they feel comfortable skipping a step, that is fine. These tools are meant to be a scaffold and therefore fade over time. Some groups might need to still lean on them heavily, and others may only need to reference them occasionally.

ADDITIONAL GUIDANCE	If your school uses APA style, you can ask students to cite each online resource like this: • Author last name, first initial. (publishing date). Title. Publisher. Web address. **Example:** • Slat, B. (2019, April 10). Whales likely impacted by Great Pacific garbage patch. The Ocean Cleanup. https://www.theoceancleanup.com/updates/whales-likely-impacted-by-great-pacific-garbage-patch/

Move around the room to support students during this time and provide feedback on their work. Consider collecting artifacts of student work at the end of class in order to provide written feedback before students complete the research cycle.

ASSESSMENT OPPORTUNITY

What to look/listen for in the moment:

- Students have gathered information, assessing the evidence and usefulness of each source using the *Evaluating Sources of Information Tool.* (SEP: 8.3).
- Students have a plan to communicate the information they get from their research. (SEP: 8.5)
- Students are obtaining and recording information related to spectra of the Universe as evidence for the Big Bang, including one or more of the following.
  - Spectra of stars tell us that most of the Universe is made of hydrogen and helium and that these elements were created in the Big Bang. (DCI: ESS1.A.2, ESS1.A.3, ESS1.A.4)
  - Spectra of galaxies tell us about their movement and distance from Earth, which supports the idea that the Universe is expanding outward from the Big Bang. (DCI: ESS1.A.2, ESS1.A.3)
  - Spectra of empty space shows lots of electromagnetic radiation, which is modeled to be the energy released in the initial Big Bang event. (DCI: ESS1.A.2, ESS1.A.3)
- Students explicitly acknowledge the connection between spectral pattern observations made by recent scientists and the Big Bang event nearly 14 billion years ago and why this evidence is convincing. (SEP: 7.2; CCC: 1.5; DCI: ESS1.A.2, ESS1.A.3)
- Use the rubric provided in *Presentation Rubric* to assess their progress on presentations in more detail.

What to do: Move around the classroom and provide feedback for students. Encourage students to carefully fill out each research tool and refer back to those tools as they prepare their presentations. Use probing questions to help students see how the information they are findings is evidence of a Big Bang event, for example:

- *What is this Big Bang idea that you have identified?*
- *Why is this radiation in empty space connected to the Big Bang?*
- *What does the spectral evidence tell us about the Universe?*
- *How does what you are explaining support or refute the Big Bang theory?*
- *How can the evidence you are considering tell us about changes in the Universe over time scales longer than we can observe?*

Building Toward 6.A.1 Read, evaluate, and communicate information about the Big Bang to explain that the theory is supported by empirical evidence of spectral patterns, including observations of distant galaxies receding from our own, of the measured composition of stars and non-stellar gasses, and of the maps of spectra of the primordial radiation. (SEP: 8.3, 8.5, 7.2; CCC: 1.5; DCI: ESS1.A.3, ESS1.A.2, ESS1.A.4)

End of day 2

5 · COMPLETE THIRD RESEARCH CYCLE

15 min

MATERIALS: *Planning for Obtaining Information Tool, Evaluating Sources of Information Tool, Obtaining Information Tool, Planning for Communicating Information Tool*

Give students time to work in their groups. If you have provided written feedback, return that to students now. Provide time at the start of class for students to polish up their research and presentation. Save at least 30 minutes for a gallery tour.

If some or all groups are finished early, pair up groups to provide peer feedback on each others' communication of information. Then allow groups to make revisions based on the feedback.

6 · TIMED GALLERY TOUR

30 min

MATERIALS: None

Look for common mechanisms and ideas in a timed gallery tour. Present **slide O**. Ask students to set up their posters, recorded presentations, research reports, or other products around the room. Then send students in their groups from station to station, giving each group four minutes per station. If students do not see every presentation, that is fine - value depth over breadth here.

As students move around the classroom, ask them to record ideas in their notebooks about common mechanisms and ideas that can help us make sense of our questions about all the matter in the Universe and how it changes over time.

As you move through the classroom, take note of and highlight ideas about the Big Bang and nucleogenesis (formation of hydrogen and helium in the Big Bang).

ASSESSMENT OPPORTUNITY	
	What to look/listen for: Use *Presentation Rubric* to assess these presentations at the end of the day.
	What to do: Use the rubric in *Presentation Rubric* to find targeted suggestions for students at different levels.
	Building Toward 6.A.2 Read, evaluate, and communicate information about the Big Bang to explain that the theory is supported by empirical evidence of spectral patterns, including observations of distant galaxies receding from our own, of the measured composition of stars and non-stellar gasses, and of the maps of spectra of the primordial radiation. (SEP: 8.3, 8.5, 7.2; CCC: 1.5; DCI: ESS1.A.3, ESS1.A.2, ESS1.A.4)

Reflect in an exit ticket. At the end of class, display **slide P** and have students complete the exit ticket prompts on the slide:
During this research cycle:

- *What obtaining, evaluating, and communicating skills did you feel you improved on?*
- *What skills are you still developing?*

End of day 3

7 · BUILDING UNDERSTANDINGS DISCUSSION

20 min

MATERIALS: None

Hold a Building Understandings Discussion about the Big Bang. Present **slide Q**. Ask, *What common mechanisms might explain all three patterns we identified across the spectra of the Universe?* Look for ideas about the Big Bang.

ASSESSMENT OPPORTUNITY	**What to look/listen for:** • Students making connections across multiple lines spectral of evidence to evaluate the Big Bang theory from the presentations of other students. (SEP: 7.2; CCC: 1.5; DCI: ESS1.A.2, ESS1.A.3, ESS1.A.4) **What to do:** Within the whole-group discussion, identify students you think might be struggling to integrate information across all research groups. Then, during the reading that follows, check in on students that had incomplete understandings in their research findings and the Consensus Discussion to make sure they access all the big ideas of the lesson. **Building Toward 6.A.3** Read, evaluate, and communicate information about the Big Bang to explain that the theory is supported by empirical evidence of spectral patterns, including observations of distant galaxies receding from our own, of the measured composition of stars and non-stellar gasses, and of the maps of spectra of the primordial radiation. (SEP: 8.3, 8.5, 7.2; CCC: 1.5; DCI: ESS1.A.3, ESS1.A.2, ESS1.A.4)

Highlight lines of evidence for the Big Bang. Present **slide R** and pose the question on the slide:

Suggested prompt	Sample student response
What evidence did we uncover from our research that supports the theory that the hydrogen and helium that makes up stars and galaxies was formed in an event called the Big Bang almost 14 billion years ago?	The amount of hydrogen and helium in stars matches models of how much hydrogen and helium were created in the Big Bang. Galaxies are redshifted, showing that the Universe is expanding. The cosmic microwave background radiation is heat left over from the Big Bang.

8 · BIG BANG READING

20 min

MATERIALS: *BigBang Theory V2* or *BigBang Theory V1*

Read about the Big Bang and respond to the prompts. Pass out *BigBang Theory V2*, which is written at a high school reading level, or *BigBang Theory V1*, which is written at a middle school reading level. Present **slide S** and explain that students should underline ideas that they recognize and circle ideas that are new to them and be ready to share those ideas with a partner. Ask students to read on their own first and respond to the prompts.

Discuss the reading with a partner. Display **slide T.** Give students about five minutes to discuss the lines of evidence and any new words or ideas with a partner.

If there is time, bring the class back together before adding to Progress Trackers to elicit new ideas from the reading.

9 · KEEP TRACK OF OUR IDEAS AND NAVIGATE

5 min

MATERIALS: science notebook

Add new words to Personal Glossaries. Display **slide U**. Ask students if there are words they should add to their Personal Glossaries. Have them discuss with an elbow partner who they did not work with today. They may want to add *Big Bang, nucleogenesis, cosmic microwave background*, or any other words they encountered in their research and found to be unfamiliar.

Remind students of the question they wanted to answer. Have a student read the question on the bottom of the slide aloud:

- *What is the composition of the whole Universe and how it has changed over time?*

Record ideas in Progress Trackers. Ask students if they have made progress on answering the question. Have them take out their *Progress Tracker*. Ask them to record what they have figured out in their Progress Trackers. Encourage them to use any combination of words, drawings,or symbols. Ideas they may record include:

- The Big Bang theory is supported by evidence.
- One line of evidence is that light/heat left over from the Big Bang can be detected across the sky. We call this radiation the cosmic microwave background. It is the right temperature for something very hot to have happened 14 billion years ago.
- Another line of evidence is that the Universe is full of galaxies that appear to be moving away from us (we know this by observing the redshift in their spectra, which gives us clues about their motion). Rewinding time on this observation, we find a hot dense Universe about 14 billion years ago.
- Another line of evidence is that we can model what elements would be created in an event like the Big Bang. H and He were created. The composition of stars (in terms of ratios of hydrogen to helium) that we observe matches predictions that come out of the Big Bang model.

ALTERNATE ACTIVITY	**Extension opportunity**: Encourage students who could benefit from an extension opportunity to research and compare various visual models for the Big Bang and the history of the Universe. This may include visualizations of the Cosmic Microwave Background, horn-shaped models of the Universe across time, or timelines of the history of the Universe. Ask students to respond to these prompts: *What do each of these models tell us about the Big Bang? How does the evidence we uncovered relate to each of these models?*

Additional Lesson 6 Teacher Guidance

SUPPORTING STUDENTS IN MAKING CONNECTIONS IN ELA	**CCSS.ELA-LITERACY.RI.11-12.7** Integrate and evaluate multiple sources of information presented in different media or formats (e.g., visually, quantitatively) as well as in words in order to address a question or solve a problem. Students gather and evaluate sources of information from online media. The sources of information in different formats have to be integrated in order to address the research questions. **CCSS.ELA-LITERACY.RST.9-10.2:** Determine the central ideas or conclusions of a text; trace the text's explanation or depiction of a complex process, phenomenon, or concept; provide an accurate summary of thetext. Students summarize the ideas from their research and consider their application to answering the research questions in their presentations. **CCSS.ELA-LITERACY.SL.9-10.4** Present information, findings, and supporting evidence clearly, concisely, and logically so that listeners can follow the line of reasoning and the organization, development, substance, and style are appropriate to purpose, audience, and task. Students present their findings clearly using a medium of their choice.

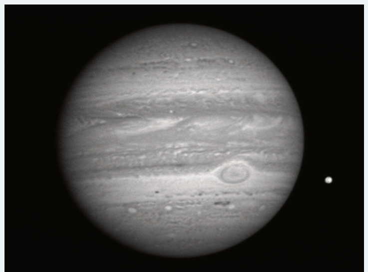
LESSON 7: How can we use the practices and crosscutting concepts we have developed to figure things out on our own?

PREVIOUS LESSON *We looked at spectra of stars, galaxies, and empty space and noticed puzzling patterns in each that might hold clues to how the matter in the Universe has changed over time. We decided to research each question and come back together to communicate our findings using the Communicating Information Planning Tool. We came to a consensus about the evidence we uncovered, which points to an event called the Big Bang, and read about what it means that people call the Big Bang a "theory." Finally, we added to our Progress Trackers and our Personal Glossaries.*

THIS LESSON

PUTTING PIECES TOGETHER

1 day



NASA/Johns Hopkins University Applied Physics Laboratory/Southwest Research Institute

We consider how the M-E-F triangle frames and our understanding of stability and change help us make sense of our phenomena. We record questions we still want answered on our DQB and then broaden to think about questions we have about other types of phenomena. We reflect on what investigations we can through online research, future science classes, a career in STEM, and/or a lifetime of curiosity. We then engage in a final transfer task.

NEXT LESSON *There is no next lesson.*

BUILDING TOWARD NGSS

HS-ESS1-1, HS-ESS1-2, HS-ESS1-3, HS-PS1-8

WHAT STUDENTS WILL DO

7.A Ask questions that arise from our life experiences about puzzling phenomena we want to explain and consider how we might obtain, evaluate, and communicate information to answer our questions going forward using the science and engineering practices and the crosscutting conceptual frames we have developed across this course and possibly the OpenSciEd High School program. (SEP: 1.1; CCC: 7.1, 5.2)

WHAT STUDENTS WILL FIGURE OUT

- Stability and change and the M-E-F triangle frames are valuable tools for making sense of our natural world.
- We can use the lenses we have developed and our research tools to continue to investigate our questions outside of class and beyond high school.

Lesson 7 • Learning Plan Snapshot

Part	Duration		Summary	Slide	Materials
1	5 min		**REFLECT ON THE CROSSCUTTING CONCEPTS** Engage in reflective discussion about the use of M-E-F frames and stability and change in the unit and class.	A-B	
2	18 min		**BUILD OUR FUTURE DQB** Review the DQB and add new questions about wider phenomena.	C-F	sticky notes, marker, Driving Question Board, Future Question Board
3	7 min		**THINK METACOGNITIVELY ABOUT OUR RESEARCH TOOLS** Consider how we can investigate our new questions and how the framing and tools we have developed can help.	G-H	
4	15 min		**TRANSFER TASK** Take the transfer task assessment for the unit.	I	*Jupiter Transfer Task*

End of day 1

Lesson 7 • Materials List

	per student	per group	per class
Lesson materials	• sticky notes • marker • *Jupiter Transfer Task*		• Driving Question Board • Future Question Board

Materials preparation (15 minutes)

Review teacher guide, slides, and teacher references or keys (if applicable).

Make copies of handouts and ensure sufficient copies of student references, readings, and procedures are available.

Lesson 7 • Where We Are Going and NOT Going

Where We Are Going

This lesson will build on the following Nature of Science elements from Appendix H of the NGSS:

- **Science is a Human Endeavor:** Scientific knowledge is a result of human endeavor, imagination, and creativity.

The lesson-level performance expectation associated with this lesson does not have a DCI component. This is because it is not intended to support the development of science ideas related to the unit. The NGSS performance expectation associated with the transfer task assessment is aligned to relevant DCIs, as listed.

This lesson is designed to coherently build on ideas related to the following science and engineering practice:

- **1.1** Ask questions that arise from careful observation of phenomena or unexpected results to clarify and/or seek additional information.

Students have asked questions across the entire course about phenomena that are presented to them. In this lesson, they expand their scope of consideration and ask questions about wider phenomena they may investigate in the future.

This lesson is designed to coherently build on ideas related to the following crosscutting concepts:

- **5.2** Changes of energy and matter in a system can be described in terms of energy and matter flows into, out of, and within that system.

Students have used the M-E-F triangle frames across the entire course, including Lessons 3 and 4 of this unit. In this lesson, they reflect on how these frames have been useful and may be in the future.

- **7.1** Much of science deals with constructing explanations of how things change and how they remain stable.

Students have used the ideas of stability and change across the course, including almost every lesson of this unit. In this lesson, they reflect on how stability and change thinking has been useful and may be in the future.

This lesson is intended to be the last lesson of the OpenSciEd High School Physics course and thus the last lesson of the OpenSciEd K-12 program. The lesson is designed to help students think metacognitively about the practices they have developed over the course, and possibly the OpenSciEd High School program, for asking and answering science questions and the crosscutting conceptual frames they can apply to help them make sense of what they figure out. They will be asked to develop a DQB of questions that we will not be able to answer in science class but that students are encouraged to pursue answers to through online research, future science classes, a career in STEM, and/or a lifetime of curiosity.

Where We Are NOT Going

The questions students develop in this lesson will not be answered in the OpenSciEd course. They are intended to show students that there are many questions left to answer and to encourage them to continue figuring out and making sense of the world around them using the tools they have developed in OpenSciEd.

LEARNING PLAN for LESSON 7

1 · REFLECT ON THE CROSSCUTTING CONCEPTS

5 min

MATERIALS: None

Present **slide A.** Have students turn and talk about the question on the slide:

- *How did the frames from the M-E-F triangle help us make sense of systems in our research and phenomena throughout this class?*

Accept all ideas. Look for students to see the utility of each of these frames on their own and together. Highlight connections students make across multiple units.

Present **slide B.** Have students turn and talk about the question on the slide:

- *How did thinking explicitly about stability and change in the Universe help us make sense of our research and phenomena throughout this class?*

Accept all ideas. Look for students to see how stability and change is fundamental to thinking productively about natural phenomena and to talk about the use of the Scale Chart. Highlight connections students make across multiple units.

2 · BUILD OUR FUTURE DQB

18 min

MATERIALS: sticky notes, marker, Driving Question Board, Future Question Board

Write down any new questions. Present **slide C**. Give students three minutes to look back at the DQB and their Progress Trackers and write down any questions. If they don't have any questions at this stage, that is fine. Have students hold on to their sticky notes.

Present **slide D**. Give students three minutes to brainstorm in their notebooks using the prompts on the slide:

- What other phenomena or design problems do you wish we had explored this year?
- What phenomena or design problems do you look forward to exploring more through your own research, talking to people you know, in future science classes, or even a career in science?
- Why are these phenomena or design problems important to you?

Write down other questions we want to pursue. Present **slide E**. Give students another three minutes to look back at their brainstorm and consider what question(s) they have about these phenomena or design problems, recording one question per sticky note.

Build the FQB. Present **slide F.** Explain that even though this physics course is over, that doesn't mean that students need to stop asking questions about the world and then using science practices and crosscutting concepts to answer them. Explain that we will use our new questions to build a Future Question Board (FQB) and brainstorm ways that students can make progress toward answering those questions on their own.

Ask for a volunteer to get the process of building the FQB started. Ask students to take responsibility for facilitating the process, using the same routines we have used to build the DQB all year. You can assign one or two students to take on the role of choosing new volunteers and keep up the momentum if the process slows down.

3 · THINK METACOGNITIVELY ABOUT OUR RESEARCH TOOLS

7 min

MATERIALS: None

Develop ideas for investigations. Present **slide G**. Give students a couple of minutes in pairs to consider the question on the slide: *What kinds of investigations could you carry out outside of this classroom, and what additional sources of data might you need to find in order to figure out the answers to some of our questions?* ✱ There is no need to share.

Reflect on our research tools and crosscutting concepts. Present **slide H.** Have students turn and talk about the question on the slide:

- *What frames or big ideas from this class might be helpful in making sense of these new questions?*
- *How do you think you might use some of the research tools we have developed in this unit to answer some of these questions?*

Once students have discussed for a couple of minutes, lead a discussion to get students ideas out on the table. Accept all ideas. Emphasize the wide breadth of ideas and skills students have developed across the course. Suggest to students that they can pursue answers to additional questions through online research using these tools on their own, in their communities, in future science classes, or even in a career in STEM.

ASSESSMENT OPPORTUNITY

What to look/listen for in the moment:

- Students considering questions they have added to the DQB that arise from our life experiences about puzzling phenomena.
- Students making connections between frames or big ideas from the course (or the OpenSciEd High School program) and their questions.
    - Especially matter, energy, and forces and stability and change as they were developed in this unit and discussed at the beginning of the lesson.

What to do: If students are having trouble making connections to crosscutting concepts, refer to the discussions at the beginning of the lesson that focused on M-E-F and stability and change.

If you have time, consider expanding this activity to do a more detailed review of the connections between units built with the crosscutting concepts.

Building Toward 7.A Ask questions that arise from our life experiences about puzzling phenomena we want to explain and consider how we might obtain, evaluate, and communicate information to answer our questions going forward using the science and engineering practices and the crosscutting conceptual frames we have developed across this course and possibly the OpenSciEd High School program. (SEP: 1.1; CCC: 7.1, 5.2)

✱ ATTENDING TO EQUITY

Remember that learning outside the classroom may take place in both formal and informal learning spaces and that context is relevant to the sources and credibility of data.

4 · TRANSFER TASK

15 min

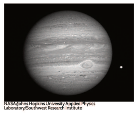
MATERIALS: *Jupiter Transfer Task*

Administer the final transfer task. Present **slide I.** Have students complete the *Jupiter Transfer Task*.

Name: ______________________ Date: ______________

Jupiter Transfer Task

Scientists have dated ancient meteorites (rocks from space) to estimate that the Solar System is approximately 5 billion years old. Five billion years ago, a cloud of mostly hydrogen collapsed due to gravity to form the Sun. A disk of dust and gas formed around the Sun. Many planets formed from this material, but the largest planet was the one we call Jupiter (pictured at right). Jupiter is so big that if the mass of all of the other planets in the Solar System were combined into one "super planet," Jupiter would still be two and a half times larger.



NASA/Johns Hopkins University Applied Physics Laboratory/Southwest Research Institute

The data below compares the sizes of Earth, Jupiter, and the Sun.

	Earth	Sun	Jupiter
Mass	1 x mass of Earth	333,000 x mass of Earth	318 x mass of Earth
Diameter	12,756 km	1,392,500 km	142,984 km
Volume	1 x Earth volume	1,300,000 x Earth volume	1,323 x Earth volume

Some people call Jupiter a “failed star.” This is because Jupiter is a ball of mostly hydrogen and helium, much like the Sun or other stars. But Jupiter is not a star and does not shine like the Sun. The light we see when we look up in the sky at Jupiter is a reflection of sunlight.

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Unit P.6 Teacher Reference Materials

ASSESSMENT SYSTEM OVERVIEW

Each OpenSciEd unit includes an assessment system that offers many opportunities for different types of assessments throughout the lessons, including pre-assessment, formative assessment, summative assessment, and student self assessment. Formative assessments are embedded and called out directly in the lesson plans. Please look for the "Assessment Icon" in the teacher support boxes to identify places for assessments. In addition, the table below outlines where each type of assessment can be found in the unit.

Overall Unit Assessment

When	Assessment and Scoring Guidance	Purpose of Assessment
Lesson 1	Initial models Driving Question Board	**Pre-Assessment** The student work in Lesson 1 available for assessment should be considered a pre-assessment. It is an opportunity to learn more about the ideas your students bring to this unit. Revealing these ideas early on can help you be more strategic in how to build from and leverage student ideas across the unit. The initial model developed in Lesson 1 is a good opportunity to pre-assess student understanding of the structure and scale of stars and the Universe. The Driving Question Board is another opportunity for pre-assessment. Reinforce for students to generate open-ended questions, such as how and why questions, and to post to the board. However, any questions students share, even if they are close-ended questions, can be valuable. Make note of any close-ended questions and use navigation time throughout the unit to have your students practice turning these questions into open-ended questions when they relate to the investigations underway.
Lesson 3	Individual models	**Formative** Students make individual models of what is happening with matter and energy within stars. Provide feedback on these models to help students capture ideas about fusion and the significance of scale within stars.
Lesson 4	Student posters	**Formative** In Lesson 4, students fill out research tools and present the findings from their research in a poster. Use this as an opportunity to formatively assess their understanding of forces within stars and what happens when a star runs out of fuel. Also use this as a check on how well students are communicating their research findings in multiple formats. Provide written feedback that students can apply within their next research cycle in Lesson 6.
Lesson 5	Individual models Electronic Exit Ticket *Electronic Exit Ticket Key for Lesson 5*	**Peer Feedback** Students make individual models before the class develops a consensus model. Students should engage in a round of peer review and revisions. Collect these models at the end of day 1 to provide feedback and identify areas that may need additional instruction before building the consensus model on day 2. **Summative** This electronic Exit Ticket addresses 3-D elements associated with the lesson-level performance expectation from Lesson 5. This assessment is designed to be easy to gather information about where your students are still struggling to put the pieces together. Use the L5 Electronic Exit Ticket Key to score the Exit Tickets across all three dimensions.

When	Assessment and Scoring Guidance	Purpose of Assessment
Lesson 6	Day 3 exit ticket *Presentation Rubric*	**Self-Assessment** Before and after the research cycle in this lesson, students reflect on their engagement in obtaining, evaluating, and communicating information. **Summative** In Lesson 6, students present the findings from their research using a medium of their choosing in a timed gallery tour. This research cycle culminates their engagement with obtaining, evaluating, and communicating information within this unit.
Lesson 7	*Jupiter Transfer Task* *Jupiter Transfer Task Key*	**Summative** At the end of this final lesson, students will have the opportunity to demonstrate their competence with a transfer task about Jupiter and the Sun.
Occurs in several lessons	Lesson Level Performance Expectation Assessment Guidance	**Formative Assessment** Use this document to see which parts of lessons or student activity sheets can be used as embedded formative assessments.
Occurs in several lessons	Progress Tracker	**Formative and Self-Assessment** The Progress Trackers are thinking tools designed to help students keep track of important discoveries that the class makes while investigating phenomena and figure out how to prioritize and use those discoveries to develop a model to explain phenomena. It is important that what the students write in the Progress Trackers reflects their own thinking at that particular moment in time. In this way, the Progress Trackers can be used to formatively assess individual student progress or for students to assess their own understanding throughout the unit. Because the Progress Tracker are meant to be a thinking tool for kids, we strongly suggest it is not collected for a summative "grade" other than for completion. In this unit, students add to their *Progress Tracker* in Lessons 2, 3, 4, and 6. Examples of models and ideas students may include in this tracker are embedded in these lessons.
Occurs in several lessons	Student Self-Assessment Discussion Rubric	**Self-Assessment** This resource is available in the OpenSciEd Teacher Handbook: High School Science. The student self-assessment discussion rubric can be used anytime after a discussion to help students reflect on their participation in the class that day. Choose to use this at least once a week or once every other week. Initially, you might give students ideas for what they can try to improve for the next time, such as sentence starters for discussions. As students gain practice and proficiency with discussions, ask for their ideas about how the classroom and small-group discussions can be more productive. In addition to this flexible resource, self-assessment has been written directly in the unit in Lesson 6.

When	Assessment and Scoring Guidance	Purpose of Assessment
Occurs in several lessons	Peer Feedback Facilitation: A Guide	**Peer Feedback** This resource is available in the OpenSciEd Teacher Handbook: High School Science. There will be times in your classroom when facilitating students to give each other feedback will be very valuable for their three-dimensional learning and for learning to give and receive feedback from others. We suggest that peer review happen at least two times per unit. This document is designed to give you options for how to support this in your classroom. It also includes student-facing materials to support giving and receiving feedback along with self-assessment rubrics where students can reflect on their experience with the process. Peer feedback is most useful when there are complex and diverse ideas visible in student work and not all work is the same. Student models or explanations are good times to use a peer feedback protocol. They do not need to be final pieces of student work, rather, peer feedback will be more valuable to students if they have time to revise after receiving peer feedback. It should be a formative, not summative, type of assessment. It is also necessary for students to have experience with past investigations, observations, and activities where they can use these experiences as evidence for their feedback. In addition to this flexible resource, peer feedback has been written directly in the unit in Lesson 5.

For more information about the OpenSciEd approach to assessment and general program rubrics, visit the OpenSciEd Teacher Handbook.

Lesson-by-Lesson Assessment Opportunities

Every OpenSciEd lesson includes one or more lesson-level performance expectations (LLPEs). The structure of every LLPE is designed to be a three-dimensional learning, combining elements of science and engineering practices, disciplinary core ideas and cross cutting concepts. The font used in the LLPE indicates the source/alignment of each piece of the text used in the statement as it relates to the NGSS dimensions: alignment to Science and Engineering Practice(s), alignment to Cross-Cutting Concept(s), and alignment to the Disciplinary Core Ideas.

The table below summarizes opportunities in each lesson for assessing every lesson-level performance expectation (LLPE). Examples of these opportunities include student handouts, home learning assignments, progress trackers, or student discussions. Most LLPEs are recommended as potential formative assessments. Assessing every LLPE listed can be logistically difficult. Strategically picking which LLPEs to assess and how to provide timely and informative feedback to students on their progress toward meeting these is left to the teacher's discretion.

Lesson	Lesson-Level Performance Expectation(s)	Assessment Guidance

Lesson	Lesson-Level Performance Expectation(s)	Assessment Guidance
Lesson 1	**1.A** Develop system models (or sets of models) to explain why the stars we see at night appear stable over time, while historical accounts of guest stars describe them changing dramatically. (SEP: 2.3; CCC: 7.1; DCI: ESS1.A.1) **1.B** Ask questions that arise from historical observations of dramatic changes in the brightness, shape, and color of stars to clarify our models, and seek additional information. (SEP: 1.1, 1.4; CCC: 7.1; DCI: ESS1.A.2)	**1.A When to check for understanding:** When students are modeling individually on day 2 and then again afterward as the class develops an Initial Consensus Model. **What look/listen for in the moment:** Look for students to: • use words, pictures, and or symbols to represent a stable star and the guest star in two separate models. (SEP: 2.3; DCI: ESS1.A.1) • indicate some mechanism (e.g., energy transfer, matter changes, or unbalanced forces) for why the guest star will change, while the typical star remains stable. It is not important that this mechanism be accurate. (CCC: 7.1; DCI: ESS1.A.1) • use features from historical accounts of guest stars in their model of stars that change.(SEP: 2.3; CCC: 7.1; DCI:ESS1.A.1) **1.B When to check for understanding:** Look for this whenever students are expressing wonderings, making models, or developing questions. Look for the assessment callout when students are building the DQB. **What look/listen for in the moment:** Look for students to ask questions (SEP: 1.1): • about the early guest star of 1054 and those they read historical accounts of in the activity. (SEP: 1.1; DCI:ESS1.A.2) • about the causes of guest stars to suddenly appear and disappear. (CCC: 7.1; DCI: ESS1.A.2) • related to uncertainties in their models of stable stars and changing guest stars. (SEP: 1.4; CCC: 7.1; DCI: ESS1.A.2) • that seek additional information about what causes guest stars to change brightness, shape, and/or color. (SEP: 1.1; CCC: 7.1; DCI: ESS1.A.2)
Lesson 2	**2.A** Integrate information from multiple spectra representations to describe differences in the composition and temperature scale of a stable star versus guest stars. (SEP: 8.2; CCC: 3.1; DCI: ESS1.A.2) **2.B** Ask questions that arise from the spectra of a guest star to seek additional information about how and why some stars appear to remain stable for so long and others change so quickly. (SEP: 1.1; CCC: 7.1; DCI: ESS1.A.2)	**2.A When to check for understanding:** After students complete their second Progress Tracker entry on **slide BB**. **What to look/listen for**: Integrate and compare across multiple spectral representations to figure out (SEP: 8.2; DCI: ESS1.A.2): • Stable stars are made of mostly hydrogen and helium. (DCI: ESS1.A.2) • Guest star remnants contain elements other than hydrogen and helium and in some cases no hydrogen or helium. (DCI: ESS1.A.2) • Guest stars are over ten times hotter than stars. (CCC: 3.1; DCI: ESS1.A.2) **2.B When to check for understanding:** When students add to the DQB on **slide DD**. **What to look/listen for**: • Questions that connect to the composition and/or the temperature of the guest star remnants. (SEP: 1.1; DCI: ESS1.A.2) • Questions that connect to whether the spectra of a stable star, guest star, or guest star remnants change over time. (SEP: 1.1; CCC: 7.1 DCI: ESS1.A.2) • Questions about if/how stars and guest stars change and why they change. (SEP: 1.1; CCC: 7.1; DCI: ESS1.A.1) • Questions about what keeps most stars stable for so long. (SEP: 1.1; CCC: 7.1)

Lesson	Lesson-Level Performance Expectation(s)	Assessment Guidance
Lesson 3	**3.A** Compare and integrate information about nuclear processes in stars and how their scale affects their significance from a list of web sources in order to obtain information to address a question and make progress on our models of why and how stars like the Sun change at the beginning and middle of their lives. (SEP: 8.2; CCC: 3.1, 5.2, 5.5; DCI: ESS1.A.4, PS1.C.1, PS3.D.4, ESS1.A.1)	**3.A.1 When to check for understanding:** At the end of day 1, collect students' *Planning for Obtaining Information Tool* and *Pre-Filled Obtaining Information Tool*. **What to look/listen for:** Look for students to work on *Planning for Obtaining Information Tool* and *Pre-Filled Obtaining Information Tool* to: • Begin considering what makes a source credible (SEP: 8.2) • Record information from multiple sites (SEP: 8.2) • Record relevant information to answer the question they chose, including ideas about fusion in the Sun or stars through the lenses of energy and matter. (SEP: 8.2; CCC: 5.2, 5.5; DCI: ESS1.A.4, PS1.C.1, PS3.D.4, ESS1.A.1) **3.A.2 When to check for understanding:** At the end of day 2, collect students' individual models. **What to look/listen for:** Look for students' models to include: • Integrated information from across multiple sources of information as well as the class discussion. (SEP: 8.2) • High heat in the core of the Sun causing particle nuclei to collide and fuse together. (CCC: 5.2; DCI: ESS1.A.1) • Particle nuclei fusing and releasing energy. (CCC: 5.5, 5.2; DCI: ESS1.A.4, PS1.C.1, PS3.D.4) • Energy transferring out of the Sun, including towards Earth. (CCC: 5.2; DCI: ESS1.A.4, PS3.D.4) • Two hydrogen atoms fuse to become one helium atom. (CCC: 5.5; DCI: PS1.C.1, ESS1.A.1) • New elements being made in stars and the possibility for heavier elements to be made if the star is massive enough. (DCI: ESS1.A.4) • The total number of protons plus neutrons are conserved, but atoms are not. (CCC: 5.5, DCI: PS1.C.1) • A large number of tiny-scale fusion reactions occurring inside a star are responsible for the enormous amounts of energy produced at the scale of the Sun. (CCC: 3.1, DCI: PS1.C.1)
Lesson 4	**4.A** Ask questions that arise from our research on fusion and from modeling the forces in stars when they are stable to clarify and seek additional information about how stars change when their fuel runs out. (SEP: 1.1, 1.4; CCC: 5.2, 7.1, 7.3; DCI: ESS1.A.4, PS3.D.4) **4.B** Gather, read, evaluate, and integrate information from multiple authoritative internet sources, assessing the evidence and usefulness of each source in answering our questions about how stars (including our Sun) remain stable and can become unstable over their life cycles and communicate the information with graphics and text. (SEP: 8.2, 8.3, 8.5; CCC: 7.1, 7.3; DCI: ESS1.A.1, ESS1.A.4, PS1.C.1)	**4.A When to check for understanding:** On day 1, as students develop research questions (**slide F**). **What to look/listen for:** • Questions that seek additional information about what we don't know about fusion and the forces inside of stars, including the Sun. (SEP: 1.1, 1.4; DCI: ESS1.A.4, PS3.D.4) • Questions about changes in matter, energy, and forces might keep a star stable or cause a stable star to become unstable. (SEP: 1.1, 1.4; CCC: 5.2, 7.1, 7.3) • Questions that will help us understand what happens to stars when their fuel runs out, including what elements can be fused within stars. (SEP: 1.1, 1.4; DCI: ESS1.A.4, PS3.D.4) **4.B.1 When to check for understanding:** At the end of day 2, collect *Evaluating Sources of Information Tool* and *Obtaining Information Tool* to formatively assess students' progress and provide written feedback. **What to look/listen for:** • Look for students to use the checklist for multiple resources and only seek to gather information once they have decided a source is credible. (SEP: 8.2, 8.3) • Look for students to record ideas from multiple sources they deem credible that are relevant to the question of what causes stars (including our Sun) to remain stable or become unstable and change. (SEP: 8.2, 8.3; DCI: ESS1.A.1, ESS1.A.4) • Students start to gather information about feedback loops (although they may not use the term) within stars between pressure out from fusion and gravity to maintain stability. (SEP: 8.3; CCC: 7.1, 7.3; DCI: ESS1.A.4) • Students start to gather information about the types of elements that stars can fuse while still remaining stable. (SEP: 8.3; CCC: 7.1; DCI: ESS1.A.4)

Lesson	Lesson-Level Performance Expectation(s)	Assessment Guidance
		• Students start to gather information about what happens when stars run out of elements they can fuse (burn out) or fuse iron. (SEP: 8.3; CCC: 7.1; DCI: ESS1.A.1, PS1.C.1) **4.B.2 When to check for understanding:** Collect the exit tickets and posters at the end of day 3. **What to look/listen for:** Look for students' posters to show: • Communication of scientific ideas about the stability and change within star systems in both graphics and text. (SEP: 8.5; CCC: 7.1, 7.3; DCI: ESS1.A.1) • Integration of the ideas they have gathered from across multiple sources to answer questions about stars' stability and change. (SEP: 8.2, 8.3; CCC: 7.1, 7.3; DCI: ESS1.A.1) • A balance (feedback loop, although they may not use the term) between inward force from gravity and outward pressure from fusion keeps stars stable. (CCC: 7.1, 7.3; DCI: ESS1.A.1, ESS1.A.4) • When fuel runs out for fusion, the balance (feedback loop) is broken and the star is not stable. (CCC: 7.1, 7.3; DCI: ESS1.A.1, ESS1.A.4) • When a star is unstable, it might puff outward (like our Sun will) or even explode if it is massive enough to fuse heavier elements (CCC: 7.1; DCI: ESS1.A.1, ESS1.A.4) • Stars (with possible connections to our Sun) changing and eventually burning out. (DCI: ESS1.A.1) • Ideas about fusion of elements up to and including iron being fused in massive stars and releasing energy. (DCI: ESS1.A.4) • When a star fuses iron, the reaction absorbs energy, causing the outward pressure to disappear, causing a catastrophic event called a supernova. (DCI: PS1.C.1) Look for student exit ticket responses to show: • Ideas about what makes some resources more useful for answering scientific questions. (SEP: 8.2, 8.3) • Ideas about gathering more useful sources. (SEP: 8.2, 8.3)

Lesson	Lesson-Level Performance Expectation(s)	Assessment Guidance
Lesson 5	**5.A** Develop and revise models based on evidence from a variety of sources to illustrate how feedback loops keep stellar systems stable and how, depending on the mass of the star, disruptions in these loops can cause sudden, catastrophic changes.(SEP: 2.3; CCC: 3.1, 7.1, 7.3; DCI: ESS1.A.4, ESS1.A.1)	**5.A.1 When to check for understanding:** Collect student models at the end of day 1 in order to assess student progress and provide written feedback. **What to look/listen for in the moment:** • Students using words and/or pictures to represent the feedback cycle that keeps star systems stable during most of their lifetimes. (SEP: 2.3; CCC: 7.3; DCI: ESS1.A.4, ESS1.A.1) • Students are modeling interactions between components of a star system at more than one moment in time to show stability and change over a stellar lifetime. (SEP: 2.3; CCC: 7.1; DCI: ESS1.A.4, ESS1.A.1) • Students identify that scale is significant within stable stars in their models because atomic-scale fusion processes within the core (one part of the star system) drive stellar-scale forces to keep the star in equilibrium. (SEP: 2.3; CCC: 3.1, 7.1, 7; DCI: ESS1.A.4, ESS1.A.1) • Students identify that the quantity of mass that a star has is significant to what happens at the end of its life because the mass of a star determines if it will be able to fuse iron or not, therefore determining if it will become a supernova and identifying that our Sun doesn't have enough mass to become a supernova and will burn out and become a red giant. (CCC: 3.1; DCI: ESS1.A.4, ESS1.A.1) • Student models illustrate fusing of elements lighter than iron (mostly hydrogen into helium) in stable stars and the fusion of iron disrupting the feedback loop, causing massive stars to become unstable and explode in a supernova. (SEP: 2.3; CCC: 7.1, 7.3; DCI: ESS1.A.4, ESS1.A.1) • Student models illustrate elements heavier than iron being fused in supernovae and left in the remnant clouds. (SEP: 2.3; DCI: ESS1.A.4) See *Example Student Models* for example student models and suggested feedback. **5.A.2 When to check for understanding:** Using the electronic Exit Ticket and accompanying key at the end of day 2. **What to look/listen for in the moment:** Use the *Electronic Exit Ticket Key for Lesson 5* to score the Exit Tickets across all three dimensions. (SEP: 2.3; CCC: 3.1; DCI: ESS1.A.4, ESS1.A.1)

<table>
<tr><th>Lesson</th><th>Lesson-Level Performance Expectation(s)</th><th>Assessment Guidance</th></tr>
<tr><td>Lesson 6</td><td>6.A Read, evaluate, and communicate information about the Big Bang to explain that the theory is supported by empirical evidence of spectral patterns, including observations of distant galaxies receding from our own, of the measured composition of stars and non-stellar gases, and of maps of radiation permeating the Universe. (SEP: 8.3, 8.5, 7.2; CCC: 1.5; DCI: ESS1.A.3, ESS1.A.2, ESS1.A.4)</td><td>6.A.1 When to check for understanding: When students are conducting their research and preparing their presentations, provide formative feedback using the bullets below.

What to look/listen for in the moment:
Students have gathered information, assessing the evidence and usefulness of each source using the Evaluating Sources of Information Tool. (SEP: 8.3)
Students have a plan to communicate the information they get from their research. (SEP: 8.5)
Students are obtaining and recording information related to spectra of the Universe as evidence for the Big Bang, including one or more of the following.
Spectra of stars tell us that most of the Universe is made of hydrogen and helium and that these elements were created in the Big Bang. (DCI: ESS1.A.2, ESS1.A.3, ESS1.A.4)
Spectra of galaxies tell us about their movement and distance from Earth, which supports the idea that the Universe is expanding outward from the Big Bang. (DCI: ESS1.A.2, ESS1.A.3)
Spectra of empty space shows lots of electromagnetic radiation, which is modeled to be the energy released in the initial Big Bang event. (DCI: ESS1.A.2, ESS1.A.3)
Students explicitly acknowledge the connection between spectral pattern observations made by recent scientists and the Big Bang event nearly 14 billion years ago and why this evidence is convincing. (SEP: 7.2; CCC: 1.5; DCI: ESS1.A.2, ESS1.A.3)
Use the rubric provided in Presentation Rubric to assess their progress on presentations in more detail.
6.A.2 When to check for understanding: Then collect the presentations at the end of day 3 and assess these presentations.

What to look/listen for in the moment:
Use Presentation Rubric to assess these presentations at the end of the day.

6.A.3 When to check for understanding: During the Building Understandings Discussion on day 3.

What to look/listen for in the moment:
Students making connections across multiple lines of spectral evidence to evaluate the Big Bang theory from the presentations of other students. (SEP: 7.2; CCC: 1.5; DCI: ESS1.A.2, ESS1.A.3, ESS1.A.4)</td></tr>
<tr><td>Lesson 7</td><td>7.A Ask questions that arise from our life experiences about puzzling phenomena we want to explain and consider how we might obtain, evaluate, and communicate information to answer our questions going forward using the science and engineering practices and the crosscutting conceptual frames we have developed across this course and possibly the OpenSciEd High School program. (SEP: 1.1; CCC: 7.1, 5.2)</td><td>When to check for understanding: When discussing the Turn and Talk about using frames and big ideas from the class and the research tools to answer further questions.

What to look/listen for in the moment:
Students considering questions they have added to the DQB that arise from our life experiences about puzzling phenomena.
Students making connections between frames or big ideas from the course (or the OpenSciEd High School program) and their questions.
Especially matter, energy, and forces and stability and change as they were developed in this unit and discussed at the beginning of the lesson.
Transfer Task PE: HS-ESS1-1 Develop a model based on evidence to illustrate the life span of the Sun and the role of nuclear fusion in the Sun's core to release energy that eventually reaches Earth in the form of radiation. (SEP: 2.3; CCC: 3.1; DCI: ESS1.A.1, PS3.D.4)</td></tr>
</table>

Lesson-Specific Teacher Materials

Lesson 3: Answer Key

L3 Research Key

Teacher note: Students may come up with ideas here that will be more salient in future lessons. Don't worry! Validate those ideas now, and we can always come back to them or add to them later. You do not need to forecast that we will get to those ideas, but if a question comes up that you know will be more relevant later, you can ask students to post them on the DQB.

Point out to students that some of these sources might overlap with other questions, and that's okay. It's hard to put together the whole picture without making those connections.

It is also okay for each student to not identify all of these ideas within the sources. The purpose of the Scientists Circle discussion is to compare and integrate across all the sources and across different students' noticings.

Planning for Obtaining Information Tool		
Goal	What is the question you are trying to answer?	**Where does the energy of stars, including our Sun, come from?**
Sub-questions and terms	Are there any additional questions you will need to answer first or terms you will need to define in order to answer the question you want to answer?	Accept all ideas. Examples of questions students might ask: • What are the mechanisms for energy transfer between the Sun and space? • How do we know energy is being transferred out of the Sun? • What "forms" of energy are inside the Sun? • How is energy stored in the Sun? • Is light transferring energy out of the Sun? • How hot is the Sun? • Do all stars transfer energy like the Sun? If students have questions outside of the scope of the lesson "what we figured out," ask them to post them to the Driving Question Board. For examples: • Will the Sun run out of energy? • Will the Sun ever become a guest star? • Will the Sun become a black hole?
Keywords	What search terms (or keywords) can you use to search that are related to this question?	Type in the whole question Energy from the Sun Energy transfer in the Sun How does the Sun make energy? Sun energy to us

Potential resources	What government agencies, universities, research institutions, online periodicals, online encyclopedias, online databases, search engines, libraries, etc. do you think might be productive places to begin searching?	NASA .gov websites Wikipedia Students might not have a lot of ideas about this yet, and that's fine.

Planning for Obtaining Information Tool		
Goal	What is the question you are trying to answer?	**What can cause the difference in the matter composition of stable stars and the remnants of guest stars?**
Sub-questions and terms	Are there any additional questions you will need to answer first or terms you will need to define in order to answer the question you want to answer?	Accept all ideas. Examples of questions students might ask: • What matter is in stars? • How can one element become another element? • What is happening inside stars like the Sun? If students have questions outside of the scope of the lesson "what we figured out," ask them to post them to the Driving Question Board. For example: • How does a stable star become a guest star? • How do guest star remnants have different matter than stable stars?
Keywords	What search terms (or keywords) can you use to search that are related to this question?	Type in the whole question Hydrogen Matter changes in stars Matter in Sun Star elements What is the Sun made out of?
Potential resources	What government agencies, universities, research institutions, online periodicals, online encyclopedias, online databases, search engines, libraries, etc. do you think might be productive places to begin searching?	NASA .gov websites Wikipedia Students might not have a lot of ideas about this yet, and that's fine.

Where does the energy of stars, including our Sun, come from?

Source	Ideas from the source that help us answer our question(s)
https://www.iaea.org/bulletin/what-is-fusion-and-why-is-it-so-difficult-to-achieve Grade level text	"we know that the sun, along with all other stars, is powered by a **reaction called nuclear fusion**." "**nuclear fusion is the process by which two light atomic nuclei combine to form a single heavier one while releasing massive amounts of energy.**" "To fuse on our sun, nuclei need to collide with each other at **very high temperatures**, exceeding ten million degrees Celsius, to enable them to overcome their mutual electrical repulsion. Once the nuclei overcome this repulsion and come within a very close range of each other, the attractive nuclear force between them will outweigh the electrical repulsion and allow them to fuse. For this to happen, the nuclei must be confined within a small space to increase the chances of collision. In the sun, the extreme pressure produced by its **immense gravity create the conditions for fusion to happen**." Students may include the diagram of fusion.
https://education.nationalgeographic.org/resource/solar-energy **(Intro Section)** Mix of grade level and advanced text	**"Solar energy is created by nuclear fusion** that takes place in the sun. **Fusion occurs when protons of hydrogen atoms violently collide in the sun's core and fuse to create a helium atom**. This process, known as a PP (proton-proton) chain reaction, **emits an enormous amount of energy. The energy, heat, and light from the sun flow away in the form of electromagnetic radiation (EMR).**" "In stars that are about 1.3 times bigger than the sun, the CNO cycle drives the creation of energy. The CNO cycle also **converts hydrogen to helium, but relies on carbon, nitrogen, and oxygen** (C, N, and O) to do so."
https://en.wikipedia.org/wiki/Sun **("Introduction" section)** Grade level text	"Every second, **the Sun's core fuses about 600 million tons of hydrogen into helium, and in the process converts 4 million tons of matter into energy.**" "When hydrogen fusion in its core has diminished to the point at which the Sun is no longer in hydrostatic equilibrium, its core will undergo a marked increase in density and temperature while its outer layers expand, eventually transforming the Sun into a red giant. It is calculated that the Sun will become sufficiently large to engulf the current orbits of Mercury and Venus, and render Earth uninhabitable – but not for about **five billion years.**"

https://www.astronomynotes.com/starsun/s3.htm Grade level text	"*Fusion* produces energy by ***fusing together*** **light nuclei like hydrogen** to make more massive nuclei like helium." "The mass that was given up to form the massive nucleus was **converted to energy**." "In the cores of main sequence stars, **four hydrogen nuclei**, each with the mass of one proton, are fused together to form a single helium nucleus **(two protons and two neutrons)** that has a mass of 3.97 times the mass of one proton." "To overcome the mutual electrical repulsion of positively-charged nuclei, a star needs extremely **high temperatures and densities**. These conditions are found only in the core of a star. Under these extreme conditions, particles move fast enough to get close enough for strong nuclear force to overcome electrical repulsion. Repulsive force increases with more positive charges. Hydrogen is fused first because it requires less extreme conditions, than the fusion of more massive nuclei." Students may include the diagram of fusion.
Students may put additional resources here	

What can cause the difference in the matter composition of stable stars and the remnants of guest stars?

Source	Ideas from the source that help us answer our question(s)
https://en.wikipedia.org/wiki/Sun **("Composition" section)** Grade level text	"The Sun is **composed primarily of the chemical elements hydrogen and helium**... The **Sun's original chemical composition was inherited from the interstellar medium out of which it formed.** **"Since the Sun formed, the main fusion process has involved fusing hydrogen into helium. Over the past 4.6 billion years, the amount of helium and its location within the Sun has gradually changed."** **"in about 5 billion years this gradual build-up will eventually cause the Sun to exit the main sequence and become a red giant."** "**heavier elements were produced by previous generations of stars** before the Sun was formed, and spread into the interstellar medium during the final stages of stellar life and by **events such as supernovae**"
https://science.nasa.gov/universe/stars/ Mix of grade level and advanced text	"After millions of years, **immense pressures and temperatures in the star's core squeeze the nuclei of hydrogen atoms together to form helium, a process called nuclear fusion**. Nuclear fusion **releases energy**, which heats the star and prevents it from further collapsing under the force of gravity." "Astronomers call stars that are **stably undergoing nuclear fusion of hydrogen into helium** main sequence stars. This is the longest phase of a star's life. **The star's luminosity, size, and temperature will slowly change over millions or billions of years during this phase. Our Sun is roughly midway through its main sequence stage."** **"A high-mass star goes further. Fusion converts carbon into heavier elements like oxygen, neon, and magnesium, which will become future fuel for the core. For the largest stars, this chain continues until silicon fuses into iron**. These processes produce energy that keeps the core from collapsing, but each new fuel buys it less and less time."
https://www.energy.gov/science/doe-explainsnucleosynthesis Mix of grade level and advanced text	"Since then, the **nuclear reactions in the life and death of stars have formed most of the other nuclei in the universe**." "Scientists believe **the heaviest naturally occurring elements, including gold, platinum and uranium, are produced in violent neutron-rich environments such as the merger of two neutron stars or supernovae.** Under these conditions, nuclei capture neutrons very quickly to produce heavier nuclei."
https://aether.lbl.gov/www/tour/elements/stellar/pp.html More accessible level text	"This process dominates in stars where the core temperature is less than 15,000,000 K (such as our sun). It consists of three reactions that result in the conversion of **six protons into a He nucleus plus two residual protons**." Students may include the diagram of fusion.

Students may put additional resources here	

Alternate Version

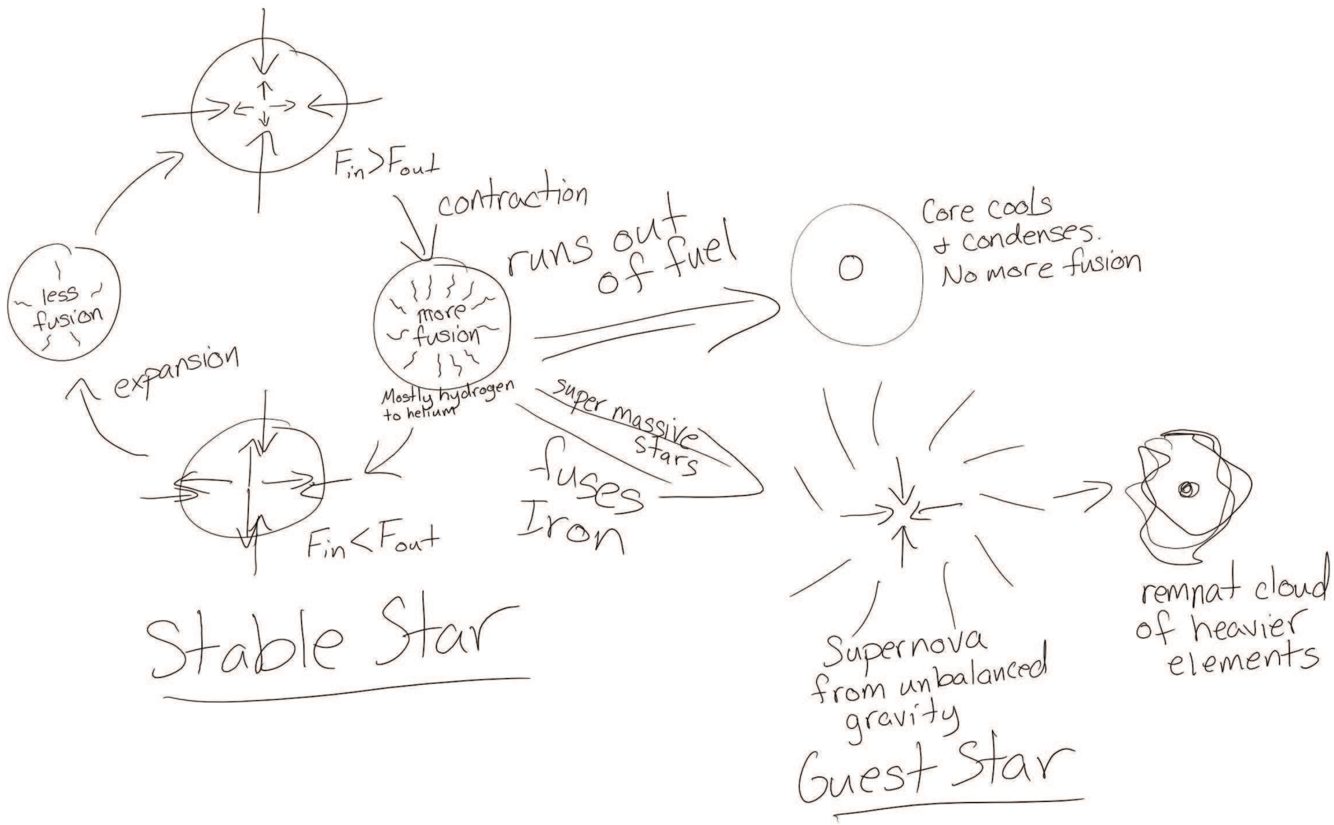
Where does the energy of stars, including our Sun, come from?

Source	Ideas from the source that help us answer our question(s)
https://spaceplace.nasa.gov/sun-heat/en/ More accessible level text	"The sun is really "big". It is so "big" that the **hydrogen atoms are pushed together with so much force that they meld into a new element called helium**. This is called **nuclear fusion**, and it **releases energy**. The energy builds up and **makes heat. It travels (transfers) outward to the surface of the Sun (the photosphere) where it is released as light, and as solar wind."** Note: this source uses the term "big" to indicate the Sun has lots of mass.
https://wonderopolis.org/wonder/how-does-the-sun-make-energy More accessible level text	"The vast amounts of hydrogen atoms in the Sun's core are **compressed and heated so much that they fuse together**. This reaction, known as **nuclear fusion, converts hydrogen atoms into helium**. The by-product of nuclear fusion in the Sun's core is a **massive volume of energy that gets released and radiates outward toward the surface of the Sun and then into the solar system beyond it**."
https://aether.lbl.gov/www/tour/elements/stellar/pp.html More accessible level text	Students may include the diagram of fusion.
Students may put additional resources here	

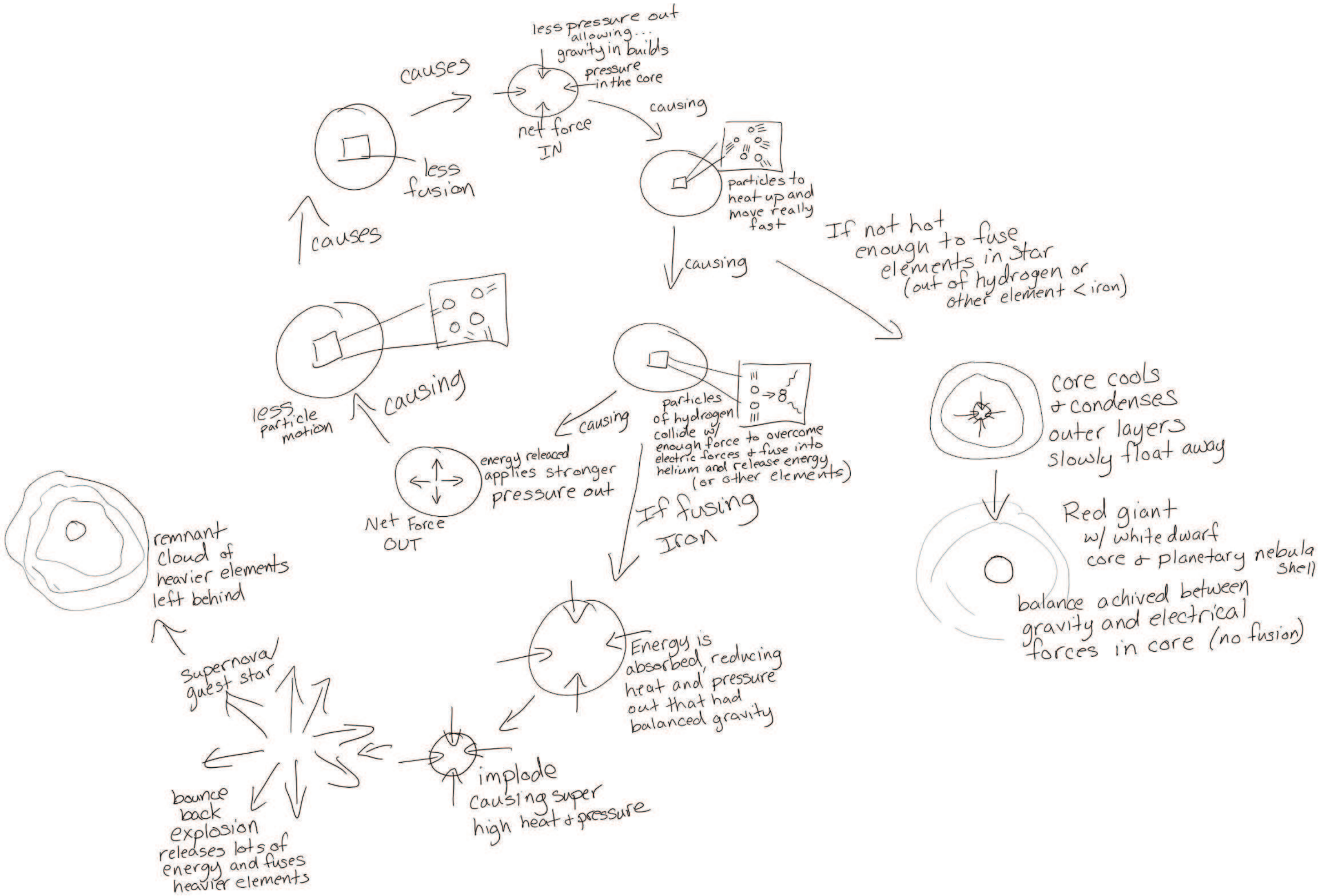
Lesson 5 Teacher Reference

Example Student Models

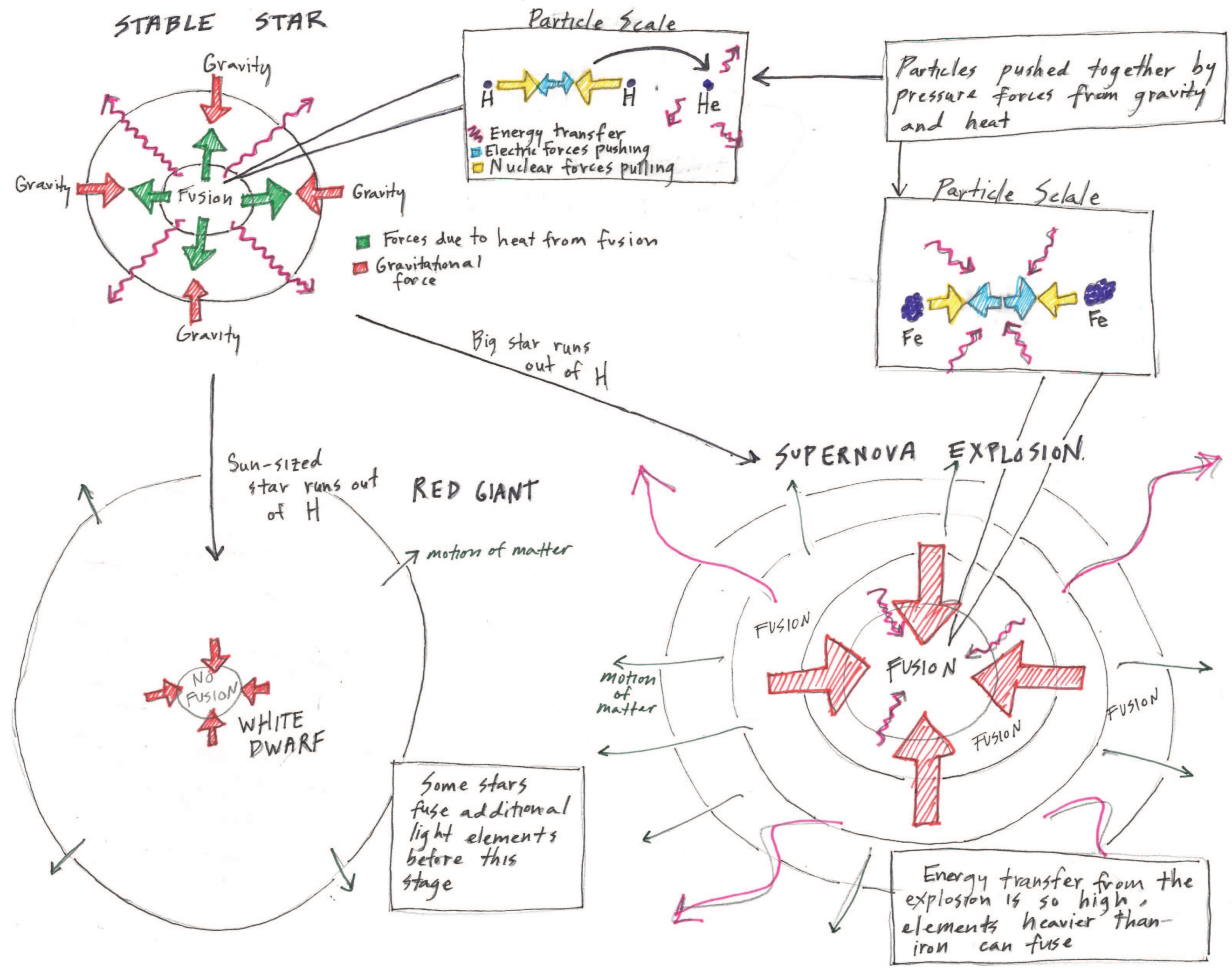
This teacher reference provides various examples of what student models may look like and brief suggestions on what feedback to provide students. All of these examples have strengths and weaknesses.



This model shows a basic but complete illustration of the feedback loop that keeps stars stable while they have fuel and what happens when that loop is disrupted. If a student makes a model like this, encourage them to add more detail, label the forces and energy or provide a key, and be more explicit about differences in the scale at which fusion is occurring.



This model shows more detail in the cause-effect steps that create the feedback loop and occur when the stability of a star is disrupted. It also models at both stellar and particle levels. However, it does not use stability and change language. Encourage this student to add labels that explicitly call out stability and change.



This model does a great job of combining the ideas from Lessons 3 and 4 in detail with the processes well documented at multiple scales. It does not however show a feedback loop. If a student makes a model like this, commend them on their process modeling and encourage them to add cause-effect relationships to create a feedback loop.

Lesson 5 Teacher Reference

Electronic Exit Tickets

What are Electronic Exit Tickets?

These are short **formative** assessments that occur 2-3 times per unit between other assessments. Since *OpenSciEd Unit P.6: Why do stars shine and will they shine forever? (Stars)* is a shorter unit, it only has one. They include items to check for understanding of LLPEs, to make connections between content and students' lives, to elicit information about students' experiences, and to help them reflect on their own progress in focal SEPs and CCCs. **These exit tickets are built in Google Forms but can be ported to any survey software.**

How to create Electronic Exit Tickets

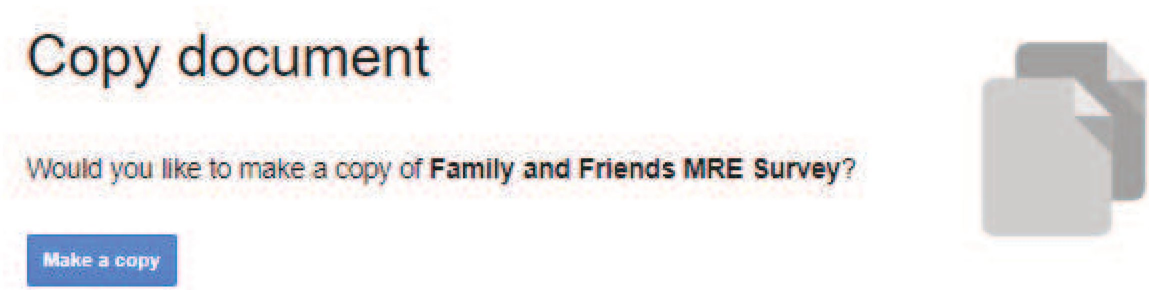
In *OpenSciEd Unit P.6: Why do stars shine and will they shine forever? (Stars)*, the unit's Electronic Exit Ticket is found at the end of Lesson 5.

Select the link for the Electronic Exit Ticket:
https://docs.google.com/forms/d/1dippcQciRvjNM6pWdC-XAywycFym6kwievoQ713w9jM/copy

Spanish versions are available here:
https://docs.google.com/forms/d/1JnnVzG6JcIKtsalStEof5vFv2WaBSfMORHHJKiHWq6o/copy

Attending to Equity
Some students may benefit from completing the Electronic Exit Ticket on a printed version. Complete the steps below to create a digital copy of the Electronic Exit Ticket in your own Google Drive. Once you have created a copy, click on the three dots in the upper right side of the form next to the SEND button. This should give you an option to print a paper copy of the Electronic Exit Ticket.

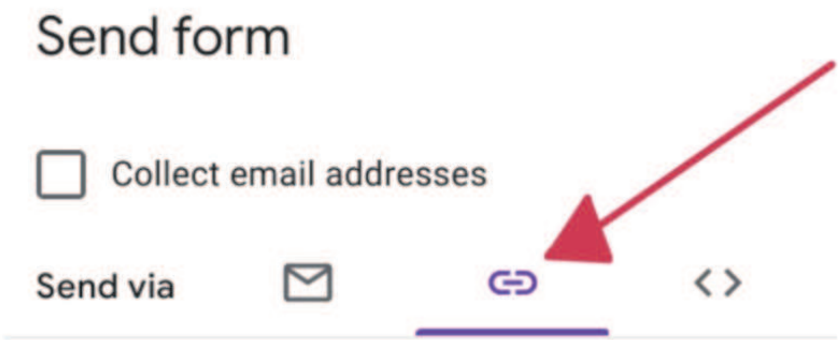
When you select the link, it will ask you to make a copy in your own Google Drive.



The student survey will open in your own Google Drive.

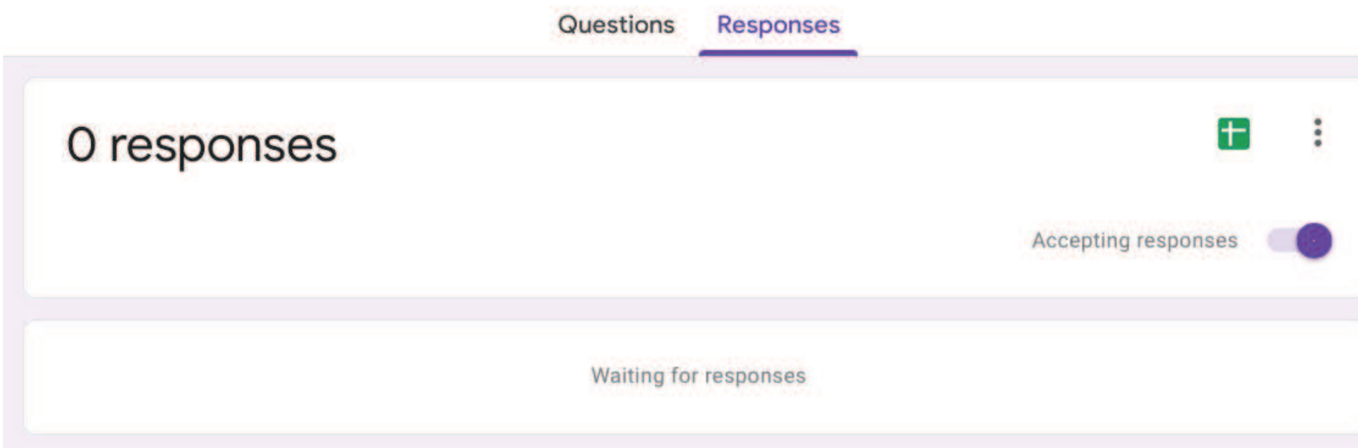
Select the “Send” button in the upper right corner to get a link to give to students.

In the “Send via” panel, select the middle icon to choose to send the survey via a link.



Copy the link it provides or select the “Shorten URL” box and then copy the link. This second option creates a link that will be easier for students to type.

Once students submit responses, these will show up in your Google Form under ”Responses.” Google will automatically provide you with some visualizations of these responses.



If you want to see the data in spreadsheet format, click the sheet icon to create a Google Sheet of your data. It will automatically populate when students respond to the survey.

For each Electronic Exit Ticket you create, you will need to repeat the process above. You can choose to make a separate ticket for each class or use the same one for all your classes.

Electronic Exit Ticket Key for Lesson 5

This electronic Exit Ticket addresses 3-D elements associated with the lesson-level performance expectations from Lesson 5, which is a putting the pieces together routine for the first lesson set of the unit. This assessment is designed to be easy to gather information about where your students are still struggling to put the pieces together.

The relevant lesson-level performance expectation is:

5.A Develop and revise models based on evidence from a variety of sources to illustrate the feedback loop processes within star systems that keep them stable and the disruptions in these loops that can cause sudden change in the system and what happens then, based on the mass of the star. (SEP: 2.3; CCC: 3.1, 7.1, 7.3; DCI: ESS1.A.4, ESS1.A.1)

The elements of these lesson-level performance expectations assessed in this Exit Ticket are:

	3D Elements Addressed in this assessment	Q1	Q2	Q3	Q4
SEPs	**2.3 Developing and Using Models.** ~~Develop, revise, and/or~~ use a model based on evidence to illustrate ~~and/or predict~~ the relationships between systems or between components of a system.	X			
CCCs	**3.1 Scale, Proportion, and Quantity.** The significance of a phenomenon is dependent on the scale, proportion, and quantity at which it occurs.		X	X	X
DCIs	**ESS1.A.4** ~~Other than the hydrogen and helium formed at the time of the Big Bang~~, nuclear fusion within stars produces all atomic nuclei lighter than and including iron, and the process releases electromagnetic energy. Heavier elements are produced when certain massive stars achieve a supernova stage and explode. (HS-ESS1- 2),(HS-ESS1-3)	X	X		
	ESS1.A.1 The star called the Sun is changing and will burn out over a lifespan of approximately 10 billion years. (HS-ESS1-1)			X	

Question 1
The surface of the Sun is about 6,000 Kelvin, or 10,000 degrees Fahrenheit. But the center of the Sun is about 15 million Kelvin. Which cause and effect model illustrates why the center of the Sun is so much hotter than the surface? (SEP: 2.3; DCI: ESS1.A.4) • **Particles fuse together in the center of the Sun, which causes energy stored in atomic nuclei to be released, which causes higher temperatures in the Sun's already dense core.** • Radioactive particles decay over time in the center of the Sun, which causes energy stored in atomic nuclei to be released, which causes higher temperatures in the Sun's already dense core. • Molecules in the center of the Sun react chemically with other compounds to produce combustion, which causes energy stored in the arrangement of atoms to be released, which causes higher temperatures in the Sun's already dense core.
What to look for: The correct answer is: **Particles fuse together in the center of the Sun, which causes energy stored in atomic nuclei to be released, which causes higher temperatures in the Sun's already dense core.** **What to do:** Point students to their Progress Trackers and to the Lesson 5 reading to support building understanding about these ideas. Be aware that these ideas depend on new scientific vocabulary that students might not be familiar with, and support students in going back to their Personal Glossaries or adding new words if necessary. If students choose radioactivity, point them to their Progress Trackers from *OpenSciEd Unit P.2: How forces in Earth's interior determine what will happen to its surface? (Earth's Interior Unit)* to review radioactive decay.

Question 2
The cloud left over after a supernova explosion is known as a supernova remnant. Supernova remnants often have elements heavier than iron, which we rarely see on the surfaces of stars. Which explanation for why supernova remnants contain heavy elements is best supported by the evidence you have collected in this unit so far? (CCC: 3.1; DCI: ESS1.A.4) • Supernovae are highly radioactive, which means that elements like hydrogen and helium will decay into heavy elements like uranium and strontium. • All fusion reactions release more energy than is required to get them started. Stars make energy by fusing every kind of element in their cores. Supernovae release the heavier elements trapped in the core of the star. • **Fusion of elements heavier than iron requires more energy to get the reaction started than will be released when the particles fuse. Supernovae are the only natural events we know about that release enough energy to make heavy elements fuse together.**
What to look for: The correct answer is: **Fusion of elements heavier than iron requires more energy to get the reaction started than will be released when the particles fuse. Supernovae are the only natural events we know about that release enough energy to make heavy elements fuse together.** **What to do:** Point students to their Progress Trackers and to the Lesson 5 reading to support building understanding about these ideas. Be aware that these ideas depend on new scientific vocabulary that students might not be familiar with, and support students in going back to their Personal Glossaries or adding new words if necessary. If students choose radioactivity, point them to their Progress Trackers from *OpenSciEd Unit P.2: How forces in Earth's interior determine what will happen to its surface? (Earth's Interior Unit)* to review radioactive decay.

Question 3

Imagine that you explained supernovae to a friend. Your friend is nervous that the Sun might run out of fuel and become a supernova. Which science-based explanation(s) should you share with your friend to reassure them? (CCC: 3.1; DCI: ESS1.A.1)

- How long a star lives depends on how massive it is. More massive stars run out of fuel quickly. The Sun is not a massive star, so it will live a long time.
- The Sun is five billion years old, and scientists predict it will remain stable for another 5 billion years before running low on hydrogen fuel.
- The Sun is not massive enough to fuse heavier elements, so when it runs out of fuel, it will not explode. Instead it will puff out its outer layers, and then the core will fade away.
- **All of the above.**

What to look for:
The correct answer is: **All of the above.**

What to do: All of the answers are correct, so make sure that students get a chance to read through the other choices again, as it is likely they simply picked a correct answer. Point students to their Progress Trackers and to the Lesson 5 reading to support building understanding about these ideas.

Question 4

The significance of a phenomenon is dependent on the scale, proportion, and quantity at which it occurs. How does this help us understand why forces exerted by particles that are too small to see can prevent a giant star from collapsing?

What to look for:
Look for students to explain that stars are very massive. Even though a single atom might not exert a big force, there are so many atoms in a star that the forces they exert on one another can prevent the star from collapsing by balancing gravity.

What to do: Use the consensus model to help students see that gravity is balanced by pressure from fusion and that these reactions happen at such a large scale that the core is able to remain stable despite the pull of gravity inward.

Lesson 6: Answer Key

Presentation Rubric

Building Toward 6.A Read, evaluate, and communicate information about the Big Bang to explain that the theory is supported by empirical evidence of spectral patterns, including observations of distant galaxies receding from our own, of the measured composition of stars and non-stellar gases, and of the maps of spectra of the primordial radiation. (SEP: 8.3, 8.5, 7.2; CCC: 1.5; DCI: ESS1.A.3, ESS1.A.2, ESS1.A.4)

Note that all students will not cover all parts of the DCIs in their individual projects. Just as the scientific community is collaborative, this project is designed to collectively compile the strands of evidence that support the Big Bang theory. All students will have a chance to learn about all components through the gallery tour and the reading.

3D Elements Addressed in the Assessment	Foundational Pieces	Linked Understanding	Organized Understanding
8.3 Obtaining, Evaluating, and Communicating Information. Gather, read, and evaluate scientific and/or technical information from multiple authoritative sources, assessing the evidence and usefulness of each source.	Students have gathered information, assessing the sources using the *Evaluating Sources of Information Tool*.	Students have gathered information from multiple sources, assessing the evidence and usefulness of each source using the *Evaluating Sources of Information Tool*.	Students have gathered information from multiple authoritative sources, assessing the evidence and usefulness of each source using the *Evaluating Sources of Information Tool*.
8.5 Obtaining, Evaluating, and Communicating Information. Communicate scientific and/or technical information or ideas (e.g., about phenomena and/or the process of development and the design and performance of a proposed process or system) in multiple formats (i.e., orally, graphically, textually, mathematically).	Students present information.	Students communicate their research findings within a single format.	Students communicate their research findings clearly, using multiple formats. This may include things such as embedding images into a written report or using visual aids in a recorded talk.
7.2 Engaging in Argument from Evidence. Evaluate the claims, evidence, and/or reasoning behind currently accepted explanations or solutions to determine the merits of arguments.	Students acknowledge the connection between observations made by scientists and the Big Bang theory.	Students state that the observations made by scientists support the Big Bang theory.	Students explain why observations made by recent scientists are convincing evidence for a Big Bang event about 14 billion years ago.
1.5 Patterns. Empirical evidence is needed to identify patterns.	Students make connections to evidence from resources but do not necessarily focus on empirical evidence.	Students mention empirical evidence but do not connect that evidence to patterns the data can be used to identify about the Universe.	Students explicitly acknowledge the connection between empirical observations made by recent scientists and the Big Bang event nearly 14 billions years ago.

ESS1.A.2 The study of stars' light spectra and brightness is used to identify compositional elements of stars, their movements, and their distances from Earth. (HS-ESS1- 2),(HS-ESS1-3) **ESS1.A.3** The Big Bang theory is supported by observations of distant galaxies receding from our own, of the measured composition of stars and non-stellar gasses, and of the maps of spectra of the primordial radiation (cosmic microwave background) that still fills the Universe. (HS-ESS1-2) **ESS1.A.4** Other than the hydrogen and helium formed at the time of the Big Bang, ~~nuclear fusion within stars produces all atomic nuclei lighter than and including iron, and the process releases electromagnetic energy. Heavier elements are produced when certain massive stars achieve a supernova stage and explode.~~ (HS-ESS1- 2),(HS-ESS1-3)	Students' presentation includes information in their own words that is derived from information on the websites that they listed as sources.	Students' presentation includes accurate information in their own words related to spectra of stars, galaxies, or empty space and the Big Bang but does not clearly make connections between the two.	Students' presentation includes accurate information in their own words related to the Big Bang and evidence for the Big Bang from spectra along one of more of the following stands: • Spectra data tells us that stars and non-stellar gasses in the Universe are mostly made of hydrogen and helium (about 74% and 25% respectively). Heavier elements only make up a tiny part of the matter of the Universe (about 1%). The Big Bang model shows the initial creation of hydrogen and helium, matching the composition we see across the Universe. • Galaxies that are farther away from us are less bright and have shifted spectra. This tells us that they are moving away from us (and each other). This supports that everything started at a central point and is now expanding outward, which is a main part of the Big Bang theory. • Empty space is full of cosmic microwave background energy, totalling more energy than all the stars. The Big Bang theory models that in the initial interaction of matter and antimatter (the Big Bang), huge amounts of energy were released. The presence of this energy in seemingly empty space supports that there must have been some event that created all this leftover energy.

	Foundational Pieces	Linked Understanding	Organized Understanding
3D Elements	**Look for:** Students have gathered information, assessing the evidence and usefulness of each source using the *Evaluating Sources of Information Tool*, and communicated information obtained from these sources. (SEP: 8.3, 8.5)	**Look for:** Students have gathered information from multiple authoritative sources, assessing the evidence and usefulness of each source using the *Evaluating Sources of Information Tool*, and communicated accurate information obtained from these sources related to the spectra of the Universe or the Big Bang. (SEP: 8.3, 8.5; DCI: ESS1.A.2, ESS1.A.3)	**Look for:** Students have gathered information from multiple authoritative sources, assessing the evidence and usefulness of each source using the Evaluating Sources Checklist, and communicated accurate information obtained from these sources related to evidence for the Big Bang, explicitly acknowledging the connection between spectral pattern observations made by recent scientists, the energy, composition, and movements of the Universe, and the Big Bang event nearly 14 billions years ago, and why this evidence is convincing. (SEP: 8.3, 8.5, 7.2; CCC: 1.5; DCI: ESS1.A.3, ESS1.A.2, ESS1.A.4)
Specific work to look for	• Students have earnestly completed the research tools. • Students have chosen websites based on the *Evaluating Sources of Information Tool*. • Students have earnestly completed a presentation, using *Planning for Communicating Information Tool* to plan. • Students' presentation includes information in their own words that is derived from information on the websites that they listed as sources.	• Students have chosen several authoritative websites based on the *Evaluating Sources of Information Tool*. • Students used *Planning for Communicating Information Tool* to plan their presentation. • Students' presentation includes accurate information in their own words related to spectra of the Universe or the Big Bang that is derived from information on the websites that they listed as sources. • Students' presentation articulates and addresses the question(s) that students set out to answer.	• Students have chosen several authoritative websites based on the *Evaluating Sources of Information Tool*. • Students used *Planning for Communicating Information Tool* to plan their presentation. • Students' presentation includes accurate information in their own words related to the connection between spectra of the Universe and the Big Bang that is derived from information on the websites that they listed as sources. • Students' presentation articulates and addresses the question(s) that students set out to answer. • Students' presentation explicitly acknowledges the connection between observations made by recent scientists and the Big Bang event nearly 14 billion years ago, and why this evidence is convincing.

	Foundational Understanding	Linked Understanding	Organized Understanding
Ideas for Instruction	Ask students to write the question they were researching at the top of a piece of paper. Then ask them to directly answer that question using information from their research and their presentation. Work with them to identify gaps in what they know and then use the Lesson 6 reading (*BigBang Theory V2* or *BigBang Theory V1*) to address those gaps. Alternatively, you can give them time to go back into their sources and look for information to fill those gaps.	Give students the chance to use the Lesson 6 reading (*BigBang Theory V2* or *BigBang Theory V1*) to help them fill in the gaps they need to answer this question. Pose the following prompt for these students as an extension writing opportunity: How do the observations that you uncovered in your research serve as evidence for a Big Bang event almost 14 billion years ago?	Encourage students who could benefit from an extension opportunity to research and compare various visual models for the Big Bang and the history of the Universe. This may include visualizations of the Cosmic Microwave Background, horn-shaped models of the Universe across time, or timelines of the history of the Universe. Ask students to respond to these prompts: What do each of these models tell us about the Big Bang? How does the evidence we uncovered relate to each of these models?

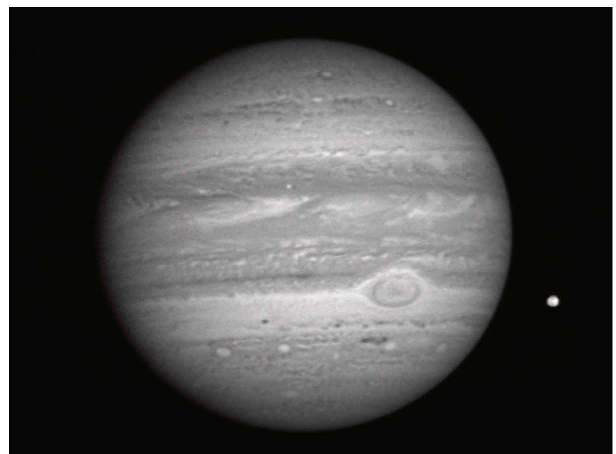
Lesson 7: Answer Key

Jupiter Transfer Task Key

HS-ESS1-1 Develop a model based on evidence to illustrate the life span of the Sun and the role of nuclear fusion in the Sun's core to release energy that eventually reaches Earth in the form of radiation. (SEP: 2.3; CCC: 3.1; DCI: ESS1.A.1, PS3.D.4)

3D Elements Addressed in the Assessment		1	2	3
SEPs	**2.3 Developing and Using Models.** Develop~~, revise,~~ and/or use a model based on evidence to illustrate and/or predict the relationships between systems or between components of a system.	X	X	
CCCs	**3.1 Scale, Proportion, and Quantity.** The significance of a phenomenon is dependent on the scale, proportion, and quantity at which it occurs.	X		X
DCIs	**ESS1.A.1: The Universe and Its Stars.** The star called the Sun is changing and will burn out over a lifespan of approximately 10 billion years.	X	X	X
	PS3.D.4: Energy in Chemical Processes and Everyday Life. Nuclear fusion processes in the center of the Sun release the energy that ultimately reaches Earth as radiation.	X		X

Scientists have dated ancient meteorites (rocks from space) to estimate that the Solar System is approximately 5 billion years old. Five billion years ago, a cloud of mostly hydrogen collapsed due to gravity to form the Sun. A disk of dust and gas formed around the Sun. Many planets formed from this material, but the largest planet was the one we call Jupiter (pictured at right). Jupiter is so big that if the mass of all of the other planets in the Solar System were combined into one "super planet," Jupiter would still be two and a half times larger.



NASA/Johns Hopkins University Applied Physics Laboratory/Southwest Research Institute

The data below compares the sizes of Earth, Jupiter, and the Sun.

	Earth	Sun	Jupiter
Mass	1 x mass of Earth	333,000 x mass of Earth	318 x mass of Earth
Diameter	12,756 km	1,392,500 km	142,984 km
Volume	1 x Earth volume	1,300,000 x Earth volume	1,323 x Earth volume

Some people call Jupiter a "failed star." This is because Jupiter is a system composed of mostly hydrogen and helium, much like the Sun or other stars. But Jupiter is not a star and does not shine like the Sun. The light we see when we look up in the sky at Jupiter is a reflection of sunlight.

1. Develop a model of the Jupiter system and a model of the Sun system to show:
    a. where the light that reaches Earth from each object comes from, and
    b. how the differences in scale between Jupiter and the Sun affect the interactions in each object's core.

Foundational pieces: Look for models that show that Jupiter is much smaller than the Sun and/or that the light coming from Jupiter is a reflection of sunlight.

Linked understanding: Look for models that show that in the center of the Sun there is fusion, and in the center of Jupiter there is not fusion.
Organized understanding: Look for models that show that there is much more pressure on the core of the Sun because of its size, causing fusion, while Jupiter does not have enough heat in the core for there to be fusion.

2. Use your model to predict what will happen to Jupiter over time.

Foundational pieces/Linked understanding: Look for predictions about how Jupiter will not change very much.
Organized understanding: Look for predictions about how Jupiter will not change very much that refer back to the model, explaining that Jupiter will most likely change in other ways, but that because it does not have fusion, it is not changing the kind of matter that it is made out of.

3. How is this different from what will happen to the Sun over time? Why?

Foundational pieces: Look for students to explain that the Sun will eventually die and/or that the Sun is much bigger than Jupiter.
Linked understanding: Look for students to explain that the Sun will run out of fuel for fusion and eventually die because it is bigger than Jupiter.
Organized understanding: Look for students to explain that the Sun is constantly changing because it is converting hydrogen to helium. Students might also mention that the Sun is stable because of a balance between gravity and fusion, and eventually this balance will shift, and the star will die. Students should also explain that it is the difference in scale that explains why the Sun is so different from Jupiter, even though they appear to be very similar phenomena (balls of hydrogen gas).