IS6

Physics in the Universe Instructional Segment 6: Stars and the Origins of the Universe

According to the NGSS storyline:

> High school students can examine the processes governing the formation, evolution, and workings of the solar system and universe. Some concepts studied are fundamental to science, such as understanding how the matter of our world formed during the Big Bang and within the cores of stars. Other concepts are practical, such as understanding how short-term changes in the behavior of our [S]un directly affect humans. Engineering and technology play a large role here in obtaining and analyzing the data that support the theories of the formation of the solar system and universe. (NGSS Lead States 2013d)

PHYSICS IN THE UNIVERSE INSTRUCTIONAL SEGMENT 6: STARS AND THE ORIGINS OF THE UNIVERSE

Guiding Questions

- How do we know what stars are made of?
- What fuels our Sun? Will it ever run out of that fuel?
- Do other stars work the same way as our Sun?
- How do patterns in motion of the stars tell us about the origin of our universe?

Performance Expectations

Students who demonstrate understanding can do the following:

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 in the form of radiation. [Clarification Statement: Emphasis is on the energy transfer mechanisms that allow energy from nuclear fusion in the sun’s core to reach Earth. Examples of evidence for the model include observations of the masses and lifetimes of other stars, as well as the ways that the sun’s radiation varies due to sudden solar flares (“space weather”), the 11-year sunspot cycle, and non-cyclic variations over centuries.] *[Assessment Boundary: Assessment does not include details of the atomic and sub-atomic processes involved with the sun’s nuclear fusion.]*

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. [Clarification Statement: Emphasis is on the astronomical evidence of the red shift of light from galaxies as an indication that the universe is currently expanding, the cosmic microwave background as the remnant radiation from the Big Bang, and the observed composition of ordinary matter of the universe, primarily found in stars and interstellar gases (from the spectra of electromagnetic radiation from stars), which matches that predicted by the Big Bang theory (3/4 hydrogen and 1/4 helium).]

PHYSICS IN THE UNIVERSE INSTRUCTIONAL SEGMENT 6: STARS AND THE ORIGINS OF THE UNIVERSE

HS-ESS1-3. Communicate scientific ideas about the way stars, over their life cycle, produce elements. [Clarification Statement: Emphasis is on the way nucleosynthesis, and therefore the different elements created, varies as a function of the mass of a star and the stage of its lifetime.] *[Assessment Boundary: Details of the many different nucleosynthesis pathways for stars of differing masses are not assessed.]*

The bundle of performance expectations above focuses on the following elements from the NRC document *A Framework for K–12 Science Education*:

Highlighted Science and Engineering Practices	Highlighted Disciplinary Core Ideas	Highlighted Crosscutting Concepts
[SEP-2] Developing and Using Models [SEP-6] Constructing Explanations (for science) and Designing Solutions (for engineering) [SEP-8] Obtaining, Evaluating, and Communicating Information	ESS1.A: The Universe and Its Stars PS3.D: Energy in Chemical Processes and Everyday Life PS4.B Electromagnetic Radiation	[CCC-3] Scale, Proportion, and Quantity [CCC-5] Energy and Matter: Flows, Cycles, and Conservation

CA CCSS Math Connections: N-Q.1–3; A-SSE.1a–b; A-CED.2, 4; MP.2; MP.4

CA CCSS for ELA/Literacy Connections: SL.11–12.4; RST.11–12.1; WHST.9–12.2.a–e

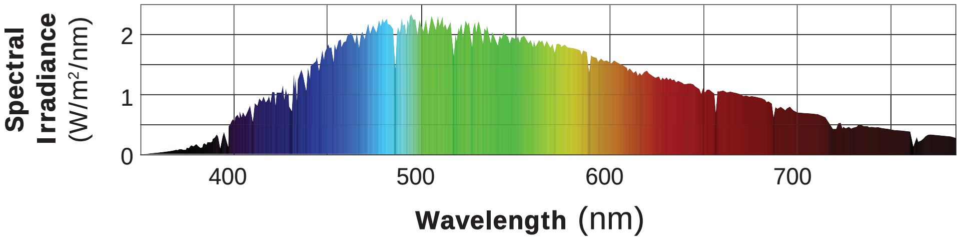
CA ELD Connections: ELD.PI.11–12.1, 5, 6a–b, 9, 10, 11a

Students now apply their understanding of electromagnetic radiation to studying the light from stars. Teachers can start this instructional segment the same way humans have for millennia by looking up in the sky and wondering what is in the heavens. In a classroom, students can zoom in and out to explore the maps of the stars and galaxies in space (such as the Sloan Digital Sky Survey/Sky Server at SDSS DR12 Navigate Tool, http://www.cde.ca.gov/ci/sc/cf/ch7.asp#link68) to engender interest in what is out there and to get a basic sense that the universe is a varied place, with dense and less dense regions of stars and gas distributed throughout it. Students discuss and share their favorite astronomical pictures and communicate to others about what they see.

The Colors of Stars

Looking carefully, students notice different stars have slightly different colors—those differences reveal a huge amount about what stars are and the way they work. When viewing the rainbow of light from our Sun through a prism, some colors appear brighter than others (figure 7.62). What causes these variations? Are they the result of errors in the equipment, something peculiar about our Sun, or a common feature of stars? Like all good science, this general observation with the naked eye can be refined with detailed measurement of specific **quantities [CCC-3]** such as the intensity of light at each wavelength (a color spectrum). Students can **obtain [SEP-8]** color spectra from many different stars using an online tool (such as the Sloan Digital Sky Survey/Sky Server, "What is Color" at http://www.cde.ca.gov/ci/sc/cf/ch7.asp#link69) and **interpret [SEP-4]** the data by comparing and noting several important **patterns [CCC-1]**. These patterns give clues about the **cause [CCC-2]** of different phenomena.

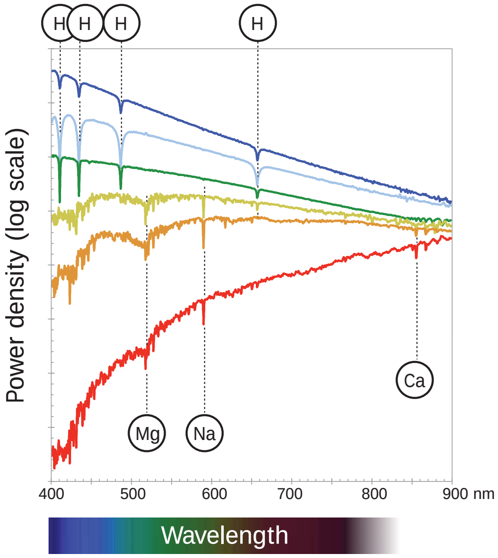
Figure 7.62. Color Spectrum of Our Sun



Color spectrum of our Sun. The rainbow image and the height of the graph depict the same information. The rainbow image is created by splitting the light from a telescope with a prism. The values of the graph are measurements of the relative intensity of each color. The graph dips lower where the rainbow image is dimmer. Graph by M. d'Alessio

Students notice that many stars have bands of low intensity at exactly the same wavelength (fig. 7.63). Understanding this observation requires additional background in physical science. The *NRC Framework* lays out strong connections between the DCIs in this instructional segment and physical science: "The history of the universe, and of the **structures [CCC-6]** and objects within it, can be deciphered using observations of their present condition together with knowledge of physics and chemistry" (National Research Council 2012, 173).

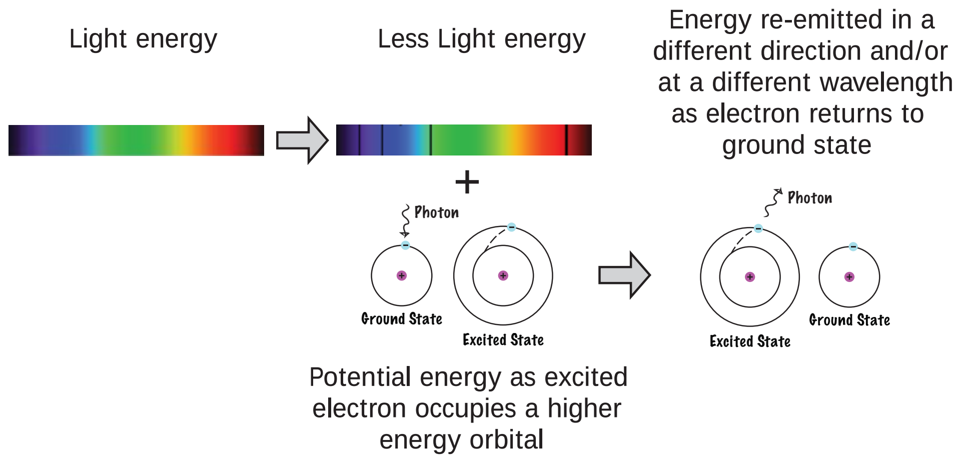
Figure 7.63. Spectra of Six Different Stars



Circles indicate spectral lines from different elements on the periodic table. Graph by M. d'Alessio with data from Sloan Digital Sky Survey/Sky Server n.d.

The concept of absorption lines in spectra from stars unites the study of matter and the study of waves. Students build upon their **model [SEP-2]** of the structure of atoms from IS4 (PS1.A; HS-PS1-8) and discover that light is a name for one segment of the electromagnetic spectrum (IS5; PS4.B; HS-PS4-1). The dark bands common in star spectra occur because atoms of different elements absorb specific colors of light (figure 7.64). Students have studied energy conversion as early as grade four and throughout the grade spans (PS3.B: 4-PS3-4, MS-PS3-3, 4, 5, HS-PS3-3; IS3), and now they are presented with a sophisticated example of individual atoms working as tiny **energy [CCC-5]** conversion devices. Atoms absorb some of the light energy (or other energy from the electromagnetic spectrum) that hits them, which pushes electrons to higher energy levels than their normal, stable ground state and temporarily store the energy as a potential energy. The atom quickly converts the energy back to light energy as it returns to its ground state, but that energy may be emitted in a completely different direction than the original energy or may be at a different wavelength. Each element on the periodic table has a unique electron orbital configuration, so different elements absorb light energy at very specific colors (wavelengths). Students can therefore use the absorption bands as fingerprints to identify the types and relative quantity of elements in a given star. Figure 7.63 shows that common star spectra include fingerprints of a number of elements, and more detailed analysis allows scientists to determine the full range of elements and even their relative abundance to construct the complete chemical composition of a star's atmosphere. For students to be able to **explain [SEP-6]** this multi-step process, the class could act out the process using their bodies to represent different components of the **system [CCC-4]** in a physical **model [SEP-2]**. Using the language of **systems [CCC-4]** helps focus student attention on the energy inputs (light), the internal workings of the system (electrons in different energy-level orbitals), and the energy outputs (light emitted in a different direction or at a different frequency than the energy input).

Figure 7.64. A Model of Absorption Lines



Absorption spectra occur because individual atoms can temporarily convert light energy into potential energy. Diagram by M. d'Alessio with images from Wereon 2006 and NASA 2010

The absorption of specific wavelengths of electromagnetic waves occurs in stars, but also all around on Earth, including in greenhouse gases in Earth's atmosphere. Materials like CO_2 and water vapor absorb infrared energy leaving the planet and re-emit it back toward Earth so that energy that would otherwise have left the system is retained. This process is fundamental to Earth's energy balance as discussed in the high school Chemistry in the Earth System course (HS-ESS2-4).

Evidence for Fusion

For ages, scientists have pondered what has caused the Sun to shine. In 1854 William Thomson (who later became so well known as a scientist that he was knighted and now is known as Lord Kelvin) published a paper calculating that the Sun would run out of fuel completely in just 8,000 years if it were made entirely of gunpowder, which was the most energy-dense self-contained fuel he could think of at the time (Kelvin 1854). Even in the 1850s, geologists had evidence that the Earth is considerably older than that, so controversy ensued over what causes the Sun to shine.

Lord Kelvin correctly determined that no chemical reaction would yield enough energy to power the Sun, but he incorrectly concluded that the Sun must be getting a constant replenishment of energy from meteors that collide with it. He died in 1907, more than a decade before scientists discovered a process that could release previously inconceivable amounts of energy, nuclear fusion (IS4). Under most conditions, when two atoms collide they bounce off one another because of the repulsive forces between their nuclei. If the atoms are moving fast enough, their nuclei may get close enough together so that when they collide, they fuse, releasing more than a million times more energy per unit of mass than any chemical reaction.

Students can repeat Lord Kelvin's **calculation [SEP-5]** about how long the Sun can last if it continues to emit energy at its current rate, but this time using information he did not have about the composition of the Sun from spectral lines (not gunpowder, but 75 percent hydrogen) and the energy release of hydrogen fusion (instead of chemical reactions). This approximate calculation of the **scale [CCC-3]** of energy release shows that the Sun's lifetime will be on the order of several billion years. Students can **support or refute the claim [SEP-7]** that this result is reasonable using evidence of the age of the Earth from IS4.

Opportunities for ELA/ELD Connections

Students select and read biographies about or autobiographies/memoirs by famous or influential scientists known for their work about the stars, Sun, planets, or universe. (Note: The teacher may provide a list of names to select from to ensure certain concepts are highlighted.) Citing evidence from text, students write a letter to the scientist asking a relevant question about their work. The letter should include a critical concept, knowledge, or discovery by the scientist and identify key ideas, words, and phrases relevant to the topic.

CA CCSS for ELA/Literacy Standards: RST.9–12.2, 4, 8; SL. 9–12.4, 5

CA ELD Standards: ELD.PI. 9–10

A Model of Fusion in Stars Over Their Lifecycle

For fusion to occur, atoms must reach a high enough temperature that they move quickly enough to fuse together, typically millions of degrees. Such temperatures do not occur naturally anywhere on Earth—they only happen in the interiors of stars where temperatures and pressures are so high due to gravity and the kinetic energy of in-falling matter. But even at the center of a star, conditions can **change [CCC-7]** that cause fusion to start and stop. As a result, we say that stars are born and die.

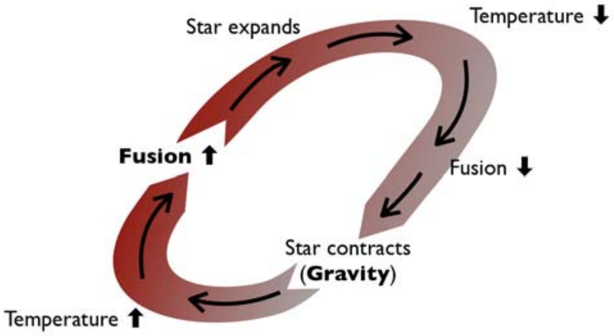
Stellar Birth and Activating Fusion

A star begins its life as a cold cloud of dust and gas. Gravity attracts the individual dust and gas particles and they fall towards one another, decreasing the gravitational potential **energy [CCC-5]** of the **system [CCC-4]**. Since energy must be conserved in the system, the particles gain kinetic energy (much like a ball falling downward speeds up as it gets lower). The temperature of an object is a measure of the average kinetic energy of its molecules, so we say that the star warms as it contracts. At some point, the particles may be moving fast enough that they undergo nuclear fusion when they collide. Within the same cloud of dust and gas, many objects can form simultaneously. Objects that accumulate enough mass to start fusion are called stars. Planets are made of the exact same material as stars and accumulate by the exact same gravitational processes, but their mass is not sufficient to begin fusion.

Mid-life as a Star: A Balance

Once fusion begins, the **energy [CCC-5]** it releases causes particles to push one another apart and the star begins to expand again. This is the opposite situation as the original star formation and involves an increase in gravitational potential energy that must be balanced by the particles slowing down (much like a ball thrown upward slows down as it gets higher). At slower speeds, fusion is less likely to occur and the star stops expanding. This counterbalancing[10] feedback between the explosive force of fusion and the attraction due to gravity keeps stars **stable [CCC-7]** during most of their lifespan (figure 7.65). This stable period of a star's life is referred to as the main sequence and it means that hydrogen is fusing in the star's core.

Figure 7.65. Counterbalancing Feedback in Stars



The explosive force of fusion balances the attractive force of gravity keeping stars **stable [CCC-7]** during most of their lives. Diagram by M. d'Alessio

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[10] In the CA NGSS standards and many textbooks, these feedbacks are called negative feedbacks. This *CA Science Framework* uses counterbalancing because many counterbalancing feedbacks have very favorable effects.

Growing Older

Even the core of a young star is not typically hot enough to fuse anything except hydrogen. Larger stars burn it more quickly because they are hotter, and all stars eventually fuse all the hydrogen in their core to form helium. At that time, fusion stops, marking the end of the period called the main sequence. Without fusion pushing the star outward, the counterbalancing feedback shown in figure 7.65 becomes unbalanced, and then gravity acts alone to contract the star.

Contraction causes temperature increases in both the core and the surrounding envelope. If the star has enough mass, it may heat enough for helium atoms to begin fusing together. If that helium gets used up, the same processes will create, in sequence, large elements up to the size of iron. Only stars that start off their lives with a large enough mass are able to generate elements larger than helium during their lifetimes. Contraction of the star's envelope triggers hydrogen to begin fusing there. The outer envelope (surrounding gaseous material) is less dense, so gravity does not act as effectively to hold the star together and fusion in the envelope causes the star to expand to a massive size, which is why some stars are called *giants* and *supergiants*.

Our Sun is currently in its main sequence, so it has not yet become a giant and still only fuses hydrogen in its core. So how does it get all the more massive elements than helium that show up in its spectra? Where did they come from?

The End of Stars

Once hydrogen fusion stops in the Sun's core, hydrogen fusion in its envelope will cause it to grow to be a giant star. Eventually its envelope will expand, leaving behind a core made primarily of carbon and oxygen. That core will still be incredibly hot and it will continue to glow for a long time even without fusion. Some of the stars we see in the night sky are actually the hot, dying cores of stars that have finished fusion.

Larger stars continue fusing atoms until they end up with only iron in their cores and spontaneous fusion stops. The core is already very dense and gravity can cause the entire core to collapse within a few seconds. This rapid core collapse leads to such high temperatures and pressures that there is finally enough extra **energy [CCC-5]** to fuse elements larger than iron. Practically all of the atoms in the universe heavier than iron formed during the cataclysmic collapse of these large stars. The collapsing core rebounds in a dramatic explosion called a supernova, ejecting all of its material out into space where it can eventually coalesce into new stars. The carbon in our bodies came from carbon made in a star that exploded and was ejected into a region of space where our solar system was born. As Carl Sagan once said, "We are made of star stuff."

Students combine their model of fusion (HS-PS1-8) with the counterbalancing feedback in figure 7.65 to construct a **model [SEP-2]** of how fusion relates to a star's lifecycle (HS-ESS1-1). They apply this model to a product that communicates how material got from the random hydrogen atoms inside a young star to the complex range of elements inside their own bodies (HS-ESS1-3). They create a diagram, storyboard, movie, or other product that illustrates this step-by-step sequence. At each stage of their diagram, they should be able to answer the question, "What is the evidence that this particular stage happens?"

Physics in the Universe Snapshot 7.14:
Asking Questions About Patterns in Stars

Investigative phenomenon: Bright stars can be located near or far from Earth, but they are typically hotter.

Students reviewed a table of a number of properties of the 100 nearest stars and the 100 brightest stars using a spreadsheet (figure 7.66). They constructed graphs of different properties looking for **patterns [CCC-1]** in the data. They found that many of the factors were uncorrelated. For example, they probably noticed that bright stars are located both near and far from Earth, but they should have seen a definite pattern between brightness and temperature—hotter stars are brighter and colder stars are dimmer. They may have begun with a linear **scale [CCC-3]**, but with such a large range in the brightness of stars (less than 1 percent as bright up to 100 times brighter than the Sun), they discovered the need to adjust to a logarithmic **scale [CCC-3]**.

Figure 7.66: How Does Star Brightness Depend on Temperature?

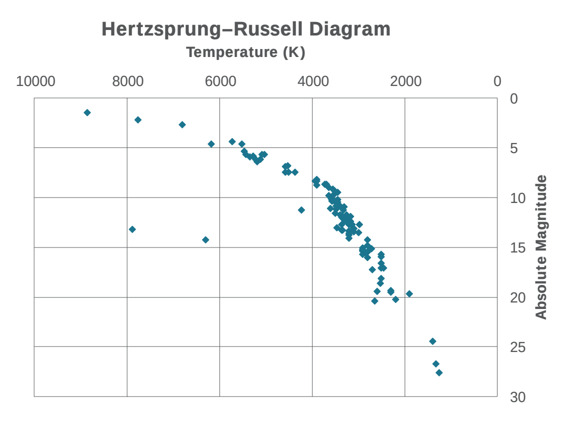


Diagram by M. d'Alessio

Physics in the Universe Snapshot 7.14:
Asking Questions About Patterns in Stars

Anaya: “Not all the bright stars are hot, though. Are those outliers?”
Cole: “And not all the dim stars are cold.”
Ms. M: “Why do you think that is? Should we graph more data?”
Jordan: “Maybe those dim ones are farther away.”
Diego: “I don’t think so. We graphed distance versus brightness and there wasn’t any trend. But I’ll look specifically at the data for those stars to make sure.”
Jordan: “Well maybe they’re smaller then. If they’re small, maybe they wouldn’t be very bright even if they were hot.”
Anaya: “And maybe those cold ones would be bright if they were really big.”

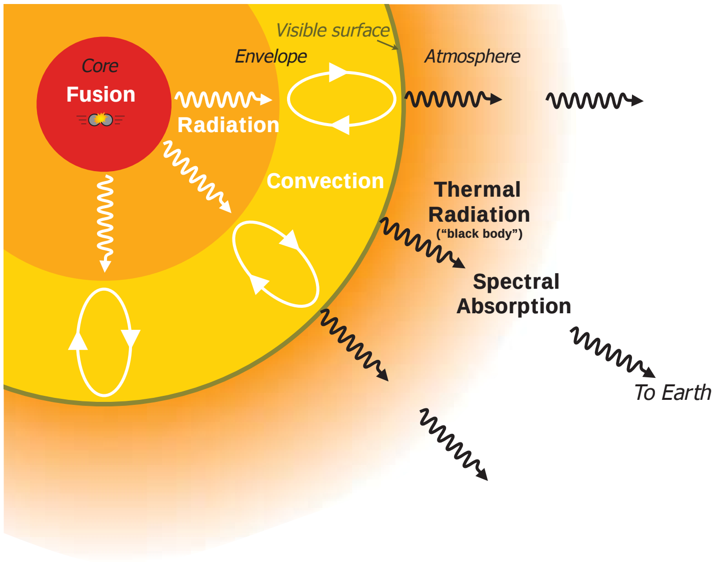
Students **asked questions [SEP-1]** that led them to further investigation. The example student dialog is idealized, but effective talk moves can help structure conversations so that students move towards this ideal (as outlined in the “Instructional Strategies” chapter of this framework).

This **pattern [CCC-1]** in the data was discovered by Ejnar Hertzsprung and Henry Russell around 1910 and is commonly referred to as a Hertzsprung-Russell (H-R) Diagram. It appears in several different forms including color (spectral type) instead of temperature. Like the coals in a fire, cooler stars are red and hotter stars are orange, yellow, or even blue. (Several online simulations are available to allow students to explore this relationship between temperature and color.) Students can add this relationship to their model of the Sun’s **energy [CCC-5]** emissions (HS-ESS1-1) because it helps explain the overall broad range of colors emitted by the Sun in figure 7.62. It relates to the star’s lifecycle because most of the stars plot along the central diagonal line in the H-R diagram, which is referred to as the *main sequence*. As each star moves through its life cycle and stops fusing elements in its core, it plots in a different section of the H-R diagram than it did during its main sequence.

Getting Energy to Earth

As early as grade five in the CA NGSS, students generated a model showing that most of the energy that we see on Earth originated in the Sun (5-PS3-1). Now students will expand their system **model [SEP-2]** to trace the **flow of energy [CCC-5]** back to fusion in the Sun’s hot core (HS-ESS1-1). Students will need to use models of heat transfer within a system such as radiation and convection from physical science (HS-PS3-4). They develop a model of convection at Earth’s surface in the middle grades (MS-ESS2-6) and in Earth’s interior in the high school Chemistry in the Earth System course. Now they can apply that model to the interior of the Sun. Convection occurs in a large section of the Sun’s outer envelope, moving heat from the interior out to the visible surface (figure 7.67). Students can directly observe evidence of this convection in high-resolution optical images of the Sun's surface that resemble a bubbling cauldron. This convection plays a role in the eruption of solar flares and other variations in solar intensity, which have been recorded for centuries (NASA 2003b). Some of these variations are periodic (the Sun's magnetic field flips about every 11 years, causing **changes [CCC-7]** in the amount of radiation of about 0.1 percent) while slightly larger variations are less well understood but can make a big difference in Earth's climate over much longer **timescales [CCC-3]** (from decades to millions of years). The existence of these variations is further evidence for convection, which constantly bubbles up new high-temperature material that emits more **energy [CCC-5]** than the cooler and denser material that sinks down. Even though no fusion occurs on the visible surface, it still shines via a process known as thermal radiation (or black body radiation). Most of this radiation travels directly towards earth, but a small fraction of it is absorbed, creating the absorption spectra of figure 7.67.

Figure 7.67. Energy Transfer from the Sun to Earth



Energy transfer by radiation and convection moves energy from the Sun's core to Earth. There are a number of steps along the way. Diagram by M. d'Alessio

Origins of the Universe

Students **analyze [SEP-4]** spectra of stars beyond the Sun by comparing them to a set of known spectral lines of different elements determined in a laboratory. To match the laboratory lines, they find that they need to shift the star spectra. Understanding the significance of this observation requires understanding of the Doppler effect, a process that builds on students' existing models of waves but is not required to meet other CA NGSS performance expectations. When stars move toward or away from a viewer, the wavelength of their light shifts. We can therefore use the Doppler shifts to map out the movements of stars toward or away from us. For example, we find that galaxies rotate, so even if overall the galaxy is moving away from us, stars on one side of it may have a smaller Doppler shift than stars on the other side. When students examine different stars in different parts of the sky, they will make the discovery that almost all galaxies are shifted toward longer wavelengths, revealing that the stars are all moving away from us. Since longer wavelengths are closer to the red end of the visible spectrum, this effect is referred to as *redshift*.

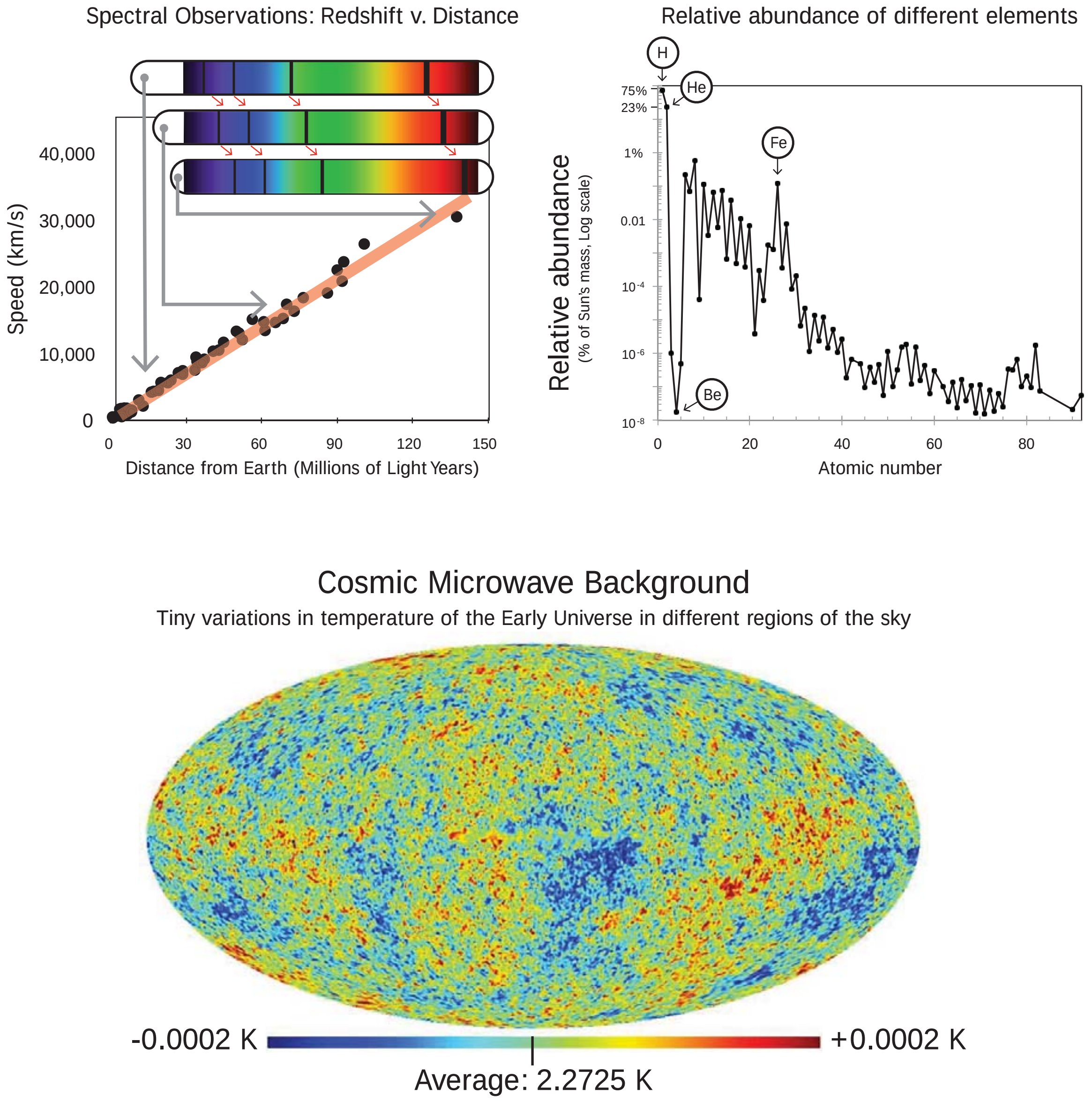
Students are now ready to **obtain information [SEP-8]** from media about Edwin Hubble's surprising discovery that the universe is expanding (see Sloan Digital Sky Survey/ Sky Server, The Expanding Universe at http://www.cde.ca.gov/ci/sc/cf/ch7.asp#link70). At the time, scientists wondered if our universe has always looked the way it does today. Einstein assumed a static, "ungrowing" universe in his equations of relativity, but others like Willem de Sitter showed that an expanding universe was also theoretically possible. Meanwhile, observational astronomers like Henrietta Leavitt developed techniques that allowed accurate distance measurements of objects in the universe, and Vesto Slipher cataloged the redshifts of entire galaxies. Hubble entered the debate by combining these techniques and noticing a **pattern [CCC-1]** in the redshifts: the farther away a galaxy is from Earth, the faster it moves away from us. Some of the most distant galaxies have such an extreme redshift that they appear to be receding from us at a speed faster than the speed of light when we calculate their velocity using Doppler shift alone. If they were moving that fast, their light would never reach us and we wouldn't be able to see them. Hubble proposed a bold **model [SEP-2]** that could **explain [SEP-6]** this pattern in which galaxies are not really moving in space, but rather the space between the galaxies is getting bigger (much like a lump of dough expanding and moving mixed-in raisins farther apart from one another). The redshifts must be the combined effect of Doppler shift and the wavelengths getting stretched by the stretching of space itself.

Students can perform their own **investigation [SEP-3]** of redshifts using simulated telescope data from online laboratory exercises. Two older examples include Project CLEA at http://www.cde.ca.gov/ci/sc/cf/ch7.asp#link71 or University of Washington Astronomy Department at http://www.cde.ca.gov/ci/sc/cf/ch7.asp#link72. This investigation requires an understanding of how distances are measured in the universe, which builds on the **argument [SEP-7]** students constructed in fifth grade that the apparent brightness of stars in the sky depends on their distance from Earth (5-ESS1-1). Students can work independently or in small groups to **obtain information [SEP-8]** about one of the methods for determining distance in the universe and then combine their findings with other students' findings to develop a report, a poster, or a presentation that describes the **scale [CCC-3]** of the universe and how it is measured.

Students now have **evidence [SEP-7]** that the universe is expanding, so teachers can invite them to **ask questions [SEP-1]** such as "What is causing this expansion?" and "What would the universe look like if we could 'rewind' this expansion to look back in time?" The inevitable answer is that everything that we can see as far as we can look out into the universe was at one time all contained in a tiny region smaller than the size of an atomic nucleus. This region was extremely hot and dense at this time until everything started rapidly to spread apart in what we call the Big Bang. We can see evidence of this expansion in the **matter and energy [CCC-5]** that exists in the universe today. As the material spread apart, it started to cool enough for atomic nuclei to form, but calculations by scientists show that only specific elements would form and in specific proportions. We can look for that "fingerprint" by using spectral lines and other techniques to determine the relative abundance of different elements in stars like our Sun (graph in the top right in figure 7.68). While Sun's relatively small proportion of heavier elements was formed in distant supernovas, its overall composition is similar to most other stars and matches the fingerprint predicted by the Big Bang with roughly three-quarters hydrogen and one-quarter helium.

In 1963, a group of scientists detected another piece of evidence of the Big Bang when they observed a constant stream of microwave radiation coming toward Earth in every direction. They were worried something was wrong with their equipment, but it became apparent that the signal they were detecting was also consistent with **models [SEP-2]** of a hot early universe that emitted radiation, which should still be traveling toward Earth today. We now call that **energy [CCC-5]** the Cosmic Microwave Background Radiation and can use it to describe what the universe looked like shortly after the initial Big Bang (image on the bottom in figure 7.68). Like so many scientific discoveries, engineering and technology have had a profound impact on scientists' ability to make measurements. Students should be able to **explain [SEP-6]** each of these pieces of evidence and the model of the Big Bang, culminating the Physics of the Universe course by combining knowledge of electromagnetic radiation, nuclear processes, gravitational forces, and even conservation of momentum.

Figure 7.68. Evidence for the Big Bang



Evidence of the Big Bang comes from the redshift versus distance of stellar spectra (top left), the relative abundance of elements in the Sun determined from absorption spectra (top right), and the Cosmic Microwave Background Radiation that reveals minute differences in temperature in the early universe (bottom). *Sources*: M. d'Alessio with data from Jha, Riess, and Kirshner 2007; M. d'Alessio with data from Lodders 2003; NASA 2008