Orion Star Trails

(Image Credit: David Malin, AAO)

In this Exploration, find out:

- *How is energy and light given off by stars?*
- *How do the different classifications of stars in the main sequence compare in size and mass?*
- *How do the sizes of stars compare to the sizes of our Sun and Earth?*

Note for the teacher: the image above is for the purpose of illustrating star colors. Many of the stars in the constellation of Orion, including Betelgeuse (upper left) and Rigel (lower right), are not on the main sequence.

Sizes of Stars Teacher's Guide

In this exercise, students will model the sizes of main sequence stars using the same scale as the Scale Model Solar System activity for the purpose of exploring the sizes of objects beyond the solar system. (Main sequence refers to stars during the main part of their "lives" during which they convert hydrogen to helium in their cores via nuclear fusion).

Recommended Prerequisite: Scale Model Solar System lesson

Grade Level: 6-8

Time Frame: The activity will take approximately 45 minutes to 1 hour to complete, including short introductions and follow-ups. Allow about 20 minutes for students to make their own calculations or give the completion of the Star Classes Table as homework before the activity.

Curriculum Standards: The Sizes of Stars lesson is matched to:

- National Science and Math Education Content Standards for grades 5-8.
- National Math Standards 5-8
- Texas Essential Knowledge and Skills (grades 6 and 8)
- Content Standards for California Public Schools (grade 8)

Purpose: To understand the scale of objects beyond the solar system, in this case the sizes of stars, to calculate scale sizes, and compare the sizes of stars to that of our own star, the Sun, and to the Earth.

Key Concepts:

- Stars are not all the same. They come in different colors, sizes, and masses.
- The Sun is a medium sized star.
- The Earth is much smaller than any star.

Required Supplies:

- A copy of the size table for each student.
- A copy of the student instruction sheet for each student .

Recommended Supplies (objects that represent stars and the Earth):

- Cherry tomato or small red ball such as a paddle ball (3 cm or about 1 inch in diameter)
- Orange
- Large grapefruit or yellow ball (14 cm or about 5 inches in diameter)
- Cantaloupe
- Volleyball
- Large blue play ball or balloon (diameter of about 43 cm or 17 inches)
- Blue candy sprinkle (such as off of a donut or sugar cookie) or Earth's planet card from the Scale Model Solar System Activity
- A metric ruler for every student or small group of students

Introduction:

Ask the students what they know (or think they know) about stars. Are they all like the Sun? What colors can stars be? (Pale blue, white, yellow, orange, and red are the common star colors.) What makes stars shine?

Concluding your introduction before passing out the student handouts for this activity will aid you in understanding the knowledge and misconceptions that the students already have.

If the students will take the student sheet home to read, try to introduce the activity in a brief discussion before the end of the class in which you will make the assignment.

Note: The use of *italics* indicates information or instructions from the student version

Review or Introduce Scale Factors:

- If your students have already done the Scale Model Solar System Activity, discuss the usefulness of the scale factor. Ask your students what the advantage would be of modeling stars on the same scale. By using the same scale factor of 1:10 billion, the students will more easily be able to make comparisons to the sizes of objects in the solar system.
- If you **have not** done the Scale Model Solar System Activity, introduce the concept of scale factors and the scale factor of 1:10 billion for this model. One good way to talk about scale factors with your students is to discuss maps. You may also want to ask your students to name other types of scale models they have seen before, such as model cars, model rockets, globes, etc.
- What does a scale factor mean? In this scale model, instead of one inch equaling 100 miles, for example, every inch in the model equals 10 billion inches in the real solar system. Similarly, 1 centimeter in this scale model equals 10 billion centimeters.

Our galaxy, the Milky Way, is filled with more than 200 billion stars! Stars come in many different sizes, colors, and masses. (The mass of an object is a measure of how much matter is in the object.)

*This activity discusses the types of stars that are in the main part of their "lives", which is called the **main sequence,** and the sizes of these different classes of stars. Stars are so big in comparison to anything here on Earth that their sizes are difficult to visualize.*

Purpose: *To understand the scale of objects beyond the solar system, in this case the sizes of stars, to calculate scale sizes, and compare the sizes of stars to that of our own star, the Sun, and to the Earth.*

> ***Background***
>
> *To help us understand the sizes of stars, we will use a **scale model.** The **scale factor** for the model (like the scale on a map) will be **1:10 billion**.*
>
> *Every centimeter for the model stars will be equal to 10 billion centimeters for a real star.*
>
> - *Our own star, the Sun, is about the size of a large grapefruit on this scale.*
> - *Earth, is tiny compared with the Sun, and in this model is only the size of a candy sprinkle.*

Why Stars Shine

What are stars made of?

Stars are almost entirely made of the gases hydrogen and helium. While they are on the main sequence, stars shine because they are converting the element hydrogen into the element helium deep inside their **cores**. Energy is given off in the process, and that energy is what allows a star to shine. The process of converting hydrogen into helium is known as **fusion.**

Why Stars Shine

This section is less critical for the key concepts, but is important in helping students understand what a main sequence star is and why stars are different colors.

A common misconception with students is that the stars are on fire, and burn just like fires on the Earth. If your students bring up such misconceptions during the introduction, gently guide them through the difficulties with this idea. Two major difficulties are the source of fuel and of oxygen to allow for a fire. A much less obvious problem is that fire, a chemical reaction, does not produce much energy in comparison with fusion. Before this century, the accepted view was that the Sun, and therefore the stars, shines because of a chemical process such as fire. If the Sun were a coal furnace, an idea from the last century, then it would run out of fuel in only a few thousand years. We know from meteorites, however, that the solar system (including the Sun) is 4.5 billion years old. The age of the Sun aside, however, such a giant fire would still require access to oxygen.

Discussing fusion with your students: The Benchmarks for Science Literacy recommend that students in the 6-8th grade be introduced to the different types of atoms, but not to subatomic particles. The discussion of fusion included in the student handout is therefore very simplified. Students may ask where the heat inside a star comes from initially so that fusion can begin. The answer is gravity. As a forming star collapses, it heats up. When the core is sufficiently dense and hot, fusion begins. The energy released by fusion keeps the star from collapsing much further. Your students may also wonder what stars are made of; they are almost entirely made of the gases hydrogen and helium.

Our own star has been a main sequence star for the last 4.5 billion years, and will continue to convert hydrogen to helium for the next 5 billion years. Not all stars are the same, however. Some stars take longer than the Sun to convert the hydrogen in their cores into helium, and other stars use up their hydrogen much more quickly.

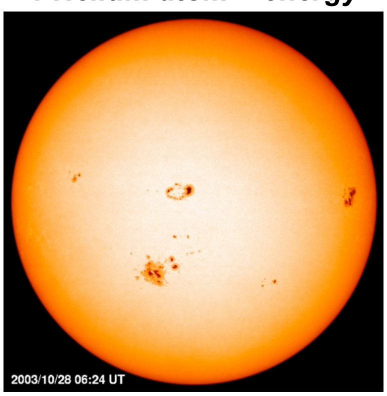
Even though fusion releases a tremendous amount of energy, a lot of heat and pressure is required to make it work. ***Where does the heat inside a star come from initially so that fusion can begin?*** *The answer is* ***gravity****. When a star is forming from the gas and dust particles in space, gravity pulls the material in towards the center. As a forming star collapses, it heats up. When the core is sufficiently dense and hot, fusion begins. The energy released by fusion keeps the star from collapsing much further.*

The ***more mass a star has, the hotter the interior of the star*** *will be, and the higher the pressure will be in the core. Hydrogen atoms are more quickly converted into helium when temperatures and pressures are higher.* ***The more mass a star has, the faster it will convert its hydrogen fuel into helium.***

Nuclear Fusion

Nuclear fusion is the nuclear reaction that converts smaller atoms into heavier atoms. Stars on the main sequence get their energy by converting hydrogen into helium through nuclear fusion.

4 Hydrogen atoms
+ heat and pressure
=
1 Helium atom + energy



(Image Credit: NASA's Solar Heliospheric Observatory)

Our Sun is a main sequence G class star. Nuclear fusion is the source of all of the Sun's energy. Deep inside our star is its core. Fusion can only happen in the hot dense core of the Sun.

A star will stay on the main sequence until there is no more hydrogen in the star's core that can be converted to ***helium.***

The energy produced by the fusion of hydrogen into helium is given off as heat. In high mass stars, fusion happens more rapidly than in low mass stars, so they produce more heat and are hotter than low mass stars.

- *Star colors are a function of temperature, with blue for a hot star and red for a cool star.*
- *The surfaces of stars are all very hot, ranging from about 3,000 K (5,000°F) to 40,000 K (70,000°F).*
- *Our own Sun has a surface temperature of 5,800 K (about 10,000°F).*
- *The cores of stars on the main sequence can be tens of millions of degrees. Our Sun has a core temperature of about 15 million K.*

Star colors as a function of temperature, with blue for a hot star and red for a cool star, may seem counter-intuitive to your students.

Blue is Hot?

Red seems hot to us because many things that are *hot here on Earth glow red, such as fires, or hot coals, or even hot lava coming out of volcanoes. However, fires and hot materials on the Earth are typically much cooler than the surfaces of stars. If a burner on an electric stove is white hot, it is hotter than a burner that is glowing red. All stars are hot. How hot the surfaces of the stars are will determine the color we see.*

- *Low mass stars are cooler, and are reddish.*
- *High mass stars are hotter, and are white or blue white.*
- *Extremely high mass stars may even shine a pale violet, which is more "blue" than blue white. High mass stars are also much brighter than low mass stars, because they produce much more energy.*

Types of Stars

Astronomers classify stars by the light they emit (or give off). Stars can be divided into seven categories (or classes) based on color: O, B, A, F, G, K, and M. (O class stars are the hottest, and M class stars are the coolest.)

One way to remember the classes of stars is by using the phrase:

***O**h **B**e **A** **F**ine **G**irl (Guy, Gorilla), **K**iss **M**e!*

Any phrase will do, as long as the words start with the letters O, B, A, F, G, K, and M.

- *What phrase can you come up with to help you remember the classes of stars?*

If time allows, ask the students to come up with, and share, their own phrases to aid them in remembering the classes of stars.

Colors of Stars

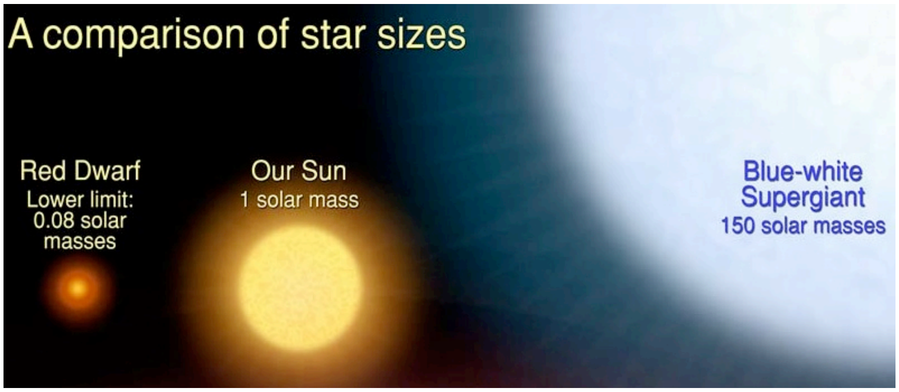
You can see stars of different colors in the night sky. Star colors are easier to see when the sky is very dark. City lights can make it hard to see star colors. You will also need to let your eyes have a chance to adapt to the dark, which usually takes a few minutes. Only very bright stars have visible colors.

Some examples of colored stars are:

- *Betelgeuse (pronounced beetle juice), a red star in the constellation Orion;*
- *Rigel, a blue white star, also in Orion; and*
- *Aldebaran, a red star in the constellation of Taurus.*

Note that the stars listed for the students are very bright and have visible colors when seen in a dark sky, especially when viewed through a telescope. However, they are not main sequence stars.

Star Sizes and Colors



On the main sequence, star sizes and colors are directly related. Larger stars are hotter and more massive than smaller stars.
(Illustration Credit: NASA, ESA and A. Feild (STScI))

Scaled Sizes of Stars Activity

Teacher Instructions:

Introduce the table containing the classes and example sizes of main sequence stars to the class.

Give each student a copy of the size table. Go over the example of how to calculate the scaled diameter of the Sun from the real diameter of the Sun and the scale factor.

Real Size / Scale Factor = Scaled Size

So

140 billion real cm / 10 billion real cm per scaled cm = 14 scaled cm

Stars are very big in comparison with the Earth, but they are also very far away.

Just how big are main sequence stars? ***Look at your STAR CLASSES TABLE.***

The <u>diameters</u> of stars of different classes are given in the STAR CLASSES Table, along with the <u>mass and color</u> of the stars in that class.

- *The diameters, masses, and colors given are for a star in the **middle** of the class (except G).*
    - *Our Sun is a G class star, and is about 10% more massive than a star in the middle of the G class. Use the Sun for our G class star just to make things easier.*

Have the students calculate the scaled diameters for the other 6 classes of stars on their own, or while working in small groups. Allow the students to devise their own methods for making the calculations, but give them suggestions if they require them.

Convert the real diameters of the stars to the scaled diameter.

- *All of the diameters of the stars are given in centimeters to make it easier for you to figure out the scaled sizes of the different stars for our model from the scale factor of 1 to 10 billion.*
- *For example, the diameter of the Sun is 140 billion centimeters. If you divide 140 billion centimeters by 10 billion centimeters, you will get the size of the model Sun, which is 14 centimeters (or about 5 inches).*
- *A large grapefruit is a good object to represent the Sun because it is about the right diameter and is yellow.*
- *Using the scale factor, calculate the scaled sizes of the other six classes of stars.*

Clever students may notice that they just need to divide the number in front of billion centimeters by 10 to get the number of scaled centimeters. Such a short cut is certainly acceptable and will make the calculations very simple.

Suggest to the students that they use their metric rulers to aid them in choosing objects of the appropriate size and color to represent each star.

What objects can you think of to represent the stars in our model?
- *Try to think of objects that are close to the right <u>size and color</u>.*
- *Use your ruler/meter stick to measure approximate sizes (you do not have to be exact, all of the star classes have a size range within them.)*

Discuss the student suggestions for objects in class. After the students have made their own suggestions, bring out the recommended objects for the different classes of stars, or objects you have selected in their places.

Recommended objects from smallest to largest:

- **M class**: a cherry tomato or small red ball that is 3 cm (or about 1 inch) in diameter
- **K class**: an orange
- **G class:** a large grapefruit or yellow ball (14 cm or about 5 inches in diameter)
- **F class:** a cantaloupe
- **A class:** a volleyball, one is probably available from your school athletic department
- **B class:** a large blue ball or balloon
- **O class:** you will most likely not have anything large enough. A light blue or purple Volkswagen Beetle or other small rounded car is close enough to the right size, and is roundish if not round. You won't be able to have one in class, but most students will probably be able to visualize it.
- **Earth:** a blue candy sprinkle

Have the students compare the candy sprinkle that represents the Earth and the grapefruit that represents the Sun to the other objects.

Follow-up:

Finish with a class discussion.

If the students have done the Scale Model Solar System Activity, have them compare the object for an M class star to the other planets in the Solar System, especially Jupiter and Saturn. Jupiter is a lot farther from being a star than many people think. Jupiter would need about 80 times its current mass to become a red dwarf M class star.

- If the question of green stars should arise, some stars (F class) do indeed produce the most light in the green part of visible light spectrum. But our eyes see these stars as pale yellow or white stars rather than as green. An excellent discussion can be found at http://outreach.atnf.csiro.au/education/senior/astrophysics/photometry_colour.html.

Discussion Questions:

1. *How did your chosen objects compare to other groups? To the teacher's?*

Some of the recommended objects are a bit small for the scaled sizes given. Your students may or may not notice this. If they do, be sure to let them know that the main sequence stars in each spectral class can be a range of sizes. The objects were selected to represent both color and be reasonable approximations for the scaled sizes of stars on our 1:10 billion scale.

2. *How much bigger or smaller than the Sun is each star? How does your answer change if you compare volumes instead of diameters?*

This question provides a good opportunity to bring in mathematic concepts related to diameter and volume.

3. *How much bigger than the Earth is each star? (The Earth has a diameter of 1.3 billion centimeters, so it is only 0.13 centimeters or 1.3 millimeters in diameter on this model.)*

The Sun is 109 times the diameter of the Earth.

4. *What did you find most surprising about the model?*

5. *The Sun is only a medium sized star. Why do you think the Sun seems so big and bright to us compared with the other stars in the sky?*

This question provides an opportunity to get students thinking about the next activity in **Stars and Planets – Stellar Distances**.