Stars and Planets

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The original idea for *Stars and Planets* was inspired by the author's work as a graduate astronomy laboratory instructor working with the Colorado Model Solar System (CMSS) on the University of Colorado at Boulder. The CMSS was originally created by Jeff Bennett, Tom Ayres, Ken Center, Ron Bass, and Matt Carter. The Introductory Astronomy Laboratory Manual containing the original CMSS activity was edited by Keith Gleason.

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Introduction to Stars and Planets

Stars and Planets is a series of nine lessons designed to assist students in grades 6-8 in understanding scale in the solar system and beyond, in time as well as space. Many of the lessons use image data from the Hubble Space Telescope and NASA's other Great Observatories as they take students on a voyage through astronomy introducing and reinforcing important concepts along the way.

Using scale in the solar system as a foundation, students will explore the properties of stars, including their formation, main sequence lifetimes, ends, what remains behind. A two-part lesson on the search for planets orbiting distant stars ties together concepts presented in the previous lessons and is designed to serve as both review and assessment. The final lesson, *A Gaggle of Galaxies*, was created to meet the middle school space science content standards from many states. The lesson extends the concept of scale in an introduction to the Milky Way and its most prominent neighbors in the local group, challenges students to create their own classification scheme for galaxies using the Hubble Ultra Deep Field, and ends with a discussion of red shift and the Big Bang.

NASA's exploration of the cosmos is highlighted in multiple lessons along with cutting-edge science. New Horizons is introduced in the *Scale Model Solar System* lesson and the Kepler Mission, a distribution partner for *Stars and Planets*, is highlighted in *Planet Hunting*. Three of the lessons feature student exploration of image data from Hubble Space Telescope (HST), and the entire series provides a wealth of teacher information and supplemental resources. Images from Solar Heliospheric Observatory (SOHO), Spitzer Space Telescope, Chandra X-Ray Observatory and references to past and future NASA missions are also included in the series of lessons.

The *Stars and Planets* sequence begins with a hands-on version of the classic scale model solar system activity that uses a scale factor of 1:10 billion for both size and distance, and then expands the idea to include stars and planets beyond the solar system using the same 1: 10 billion scale. Mathematics plays a central role in each activity. In addition to scale models of size, distance, and time, probability and conditional probability will be introduced in the context of star birth. Each lesson blends practical applications of mathematical modeling with up-to-date accurate astronomical content, guiding students in an exploration of the cosmos and in development of an understanding of "our place in space".

Stars and Planets is intended to build a firm conceptual foundation for understanding important astronomical concepts. Each lesson is designed to build upon concepts presented in prior lessons, but is also modular to allow for flexibility in adapting to classroom curriculum requirements.

Scale Model Solar System: In this exercise (based on the Colorado Model Solar System on the Campus of the University of Colorado at Boulder), students create their own scale model solar systems from common materials for the purpose of exploring concepts of size and distance in the solar system. The same scale factor is used for both size and distance. On a scale of 1 to 10 billion, the sun is the size of a large grapefruit, the Earth is the size of a candy sprinkle, and Jupiter is the size of a marble. A space of only 80 m, which can easily be accommodated on most school grounds, allows students to make a distance model from the sun to Jupiter and to see the difference in spacing between the inner and outer planets. An updated version of this activity was created following the reclassification of Pluto as a dwarf planet in 2006.

Key concepts include:

- All planets are much smaller than the sun.
- The Earth is a relatively small planet.
- The solar system is mainly empty space.
- The scale of the solar system is immense.
- The small inner planets are much closer to the sun than are the outer planets.

Sizes of Stars: Students model the sizes of main sequence stars with every day objects using the same scale as the Scale Model Solar System activity, and compare the sizes of stars of different classes (on this scale ranging from the size of a cherry to a small car) to the Sun and Earth.

Key concepts include:

- 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 main sequence star.

Distances of Stars: Using maps, students will plan a scale model to explore the distances between stars, focusing on Alpha Centauri, the system of stars nearest to the sun. This activity will build upon the activity Sizes of Stars, and once again uses a scale factor of 1 to 10 billion.

Key concepts include:

- Distances between stars are immense compared with the sizes of stars.
- The planets are much closer to the Sun than to the next closest star.

On a model with a scale of 1 to 10 billion, the distance between Alpha Centauri and the model sun is roughly equal to the width of the continental United States.
Map courtesy of www.theodora.com/map. Used with permission.

Star Birth: Students learn about the birth of stars in interstellar clouds of gas and dust. This activity differs from the previous lessons in the set in that will not involve scale models. Rather, students will use a hands-on exercise in probability to learn about the relative number of main sequence stars of different classes (masses) that are born in a typical stellar nursery. An Internet extension is also provided in which students compare and contrast images of different stellar nurseries imaged by the Hubble Space Telescope.

Key concepts include:

- Stars are different ages.
- Stars are born in giant clouds of gas and dust.
- Many more low mass (cool) stars are born than high mass (hot) stars.

Lifetimes of Stars: In this activity, students return to the concept of a scale model to make a scale model of time rather than distance. The lifetimes of different masses of stars are compared to each other and to the geologic timeline for the Earth. Students then make predictions about what classes of main sequence stars might have planets with interesting life forms (as defined by the students), assuming the history of life on Earth is typical.

Key concepts include:

- How long a star shines is very dependent on its mass.
- Low mass stars have less hydrogen to convert to helium than do high mass stars, but live much longer.
- Our sun has lived about half of its life as a main sequence star.
- For most of the history of the Earth (and the sun), bacteria and other microorganisms were the only form of life on our planet.
- The lifetimes of stars are relevant to the search for life on extrasolar planets.

Death of Stars: Each of the previous activities on the topic of stars dealt with stars on the Main Sequence. In Death of Stars, students will once again use a scale factor of 1 to 10 billion. Working individually or in small groups, students will determine the scaled sizes of exotic objects such as red giants and super giants, white dwarfs, and black holes. They will then compare the sizes of dying stars and stellar remnants to the scaled sizes of the sun, Earth, distances in the Scale Model Solar System, and a Main Sequence M class (red) star from the previous activities.

Key concepts include:

- Dying stars can be much bigger than main sequence stars.
- The objects that are left behind when a star dies (a white dwarf, neutron star, or black hole) are the size of the Earth or smaller.
- Our sun will never go supernova.

Planet Hunting: This two-part activity in *Stars and Planets* brings together many of the concepts presented in the other lessons in an investigation of the challenges astronomers face in the ongoing search for extrasolar planets. In part 1, students begin with a discussion of why Uranus, Neptune, and all of the dwarf planets in our own solar system weren't discovered until after the invention of telescopes. Turning to the search for extrasolar planets, students will draw upon knowledge from the previous lessons, and some new demonstrations, as they discuss the challenges presented by the size, distance, and the brightness of stars. Finally, students learn of the clever techniques astronomers use to find planets without "seeing" them. In part 2, students learn about the discoveries of Jupiter-like planets around other stars and make scale models of several of these planetary systems to compare to our own solar system. The students are also be introduced to current planet hunting efforts, and future projects such as Kepler and Terrestrial Planet Finder that hold the promise of finding Earth-like planets around main sequence stars.

Key concepts include:

- Planets shine by reflecting light from their parent star.
- Stars are much brighter than planets.
- Planets can be detected without being "seen".
- Earth-like planets are much harder to find than Jupiter-like planets.
- No Earth-like planets orbiting other normal stars have been found so far.

"Trying to see the Earth from Alpha Centauri would be like trying to see a candy sprinkle on a donut in New York when you are standing in San Francisco!" - from Planet Hunting.

A Gaggle of Galaxies: A Gaggle of Galaxies was added to the Stars and Planets sequence to meet the requirements of middle school space science content standards in several states. In A Gaggle of Galaxies students learn about our own Milky Way, the local group of galaxies, and create their own classification scheme for galaxies in the Hubble Ultra Deep Field, an image of galaxies just 400 to 800 million years after the Big Bang. Students will then have an introduction to the concept of red shift and how it relates to the Big Bang Theory for the origin of the Universe .In their exploration of galaxies students will move from the 1 to 10 billion scale model used with stars to one showing the size of the Milky Way in comparison to the spacing between galaxies in the Local Group. Images of our galactic neighbors are provided for the teacher to enrich the introduction to galaxies beyond our own.

Key concepts include:

- Our galaxy, the Milky Way, is a barred spiral containing 200 to 500 billion stars.
- Our own galaxy is one of hundreds of billions of galaxies in the known universe.
- Galaxies are closer together in comparison with their size than are stars.
- Galaxies can take many different forms.
- Galaxies are classified by their morphology.
- The red shift of galaxies in the Hubble Ultra Deep Field is evidence for the Big Bang.

Links to National Standards: Each lesson in the *Stars and Planets* sequence meets several National content standards for science and mathematics. Because of the large number of standards we intend to meet, links to general categories for the 5-8th grade *National Science Education Standards* (NSES) and the 6-8th grade *Principles and Standards for School Mathematics* (PSSM) are given in Tables 1 and 2 respectively. Examples of NSES content standards that will be met by the lessons include:

- From D, Space Sciences: "The earth is the third planet from the sun in a system that includes the moon, the sun, eight other planets and their moons, and smaller objects, such as asteroids and comets. The sun, an average star, is the central and largest body in the solar system.
- From B, Physical Sciences: "The sun is a major source of energy for changes on the earth's surface. The sun loses energy by emitting light. A tiny fraction of that light reaches the earth, transferring energy from the sun to the earth."
- From A, Science as Inquiry: "Mathematics is important in all aspects of scientific inquiry."

Table 1: Matching of Individual Lesson Plans to NSES Content Standards for Grades 5-8

Lesson Plans	*Unifying Concepts Processes*	*Science as Inquiry*	*Physical Science*	*Life Science*	*Earth & Space Science*	*History & Nature of Science*
Scale Model Solar System, Part 1	X	X			X	
Part 2	X	X			X	
Sizes of Stars	X	X	X		X	
Distances of Stars	X	X				
Star Birth	X	X	X			X
Lifetimes of Stars	X	X		X	X	
Death of Stars	X	X	X			
Planet Hunting, Part 1	X	X	X			X
Planet Hunting, Part 2	X	X				X
Gaggle of Galaxies	X	X			X	X

Table 2: Matching of Individual Lesson Plans to PSSM Standards for Grades 6-8

Lesson Plans	*Number & Operation*	*Measurement*	*Data Analysis & Probability*	*Problem Solving*	*Connections*	*Represent -ation*
Scale Model Solar System, Part 1	X	X		X	X	X
Part 2	X	X		X	X	X
Sizes of Stars	X	X	X	X	X	X
Distances of Stars	X	X	X	X	X	X
Star Birth	X		X	X	X	X
Lifetimes of Stars	X	X	X	X	X	X
Death of Stars	X	X	X	X	X	X
Planet Hunting, Part 1	X	X		X	X	X
Part 2	X	X	X	X	X	X
Gaggle of Galaxies	X			X	X	X

In addition to matches to content standards, the *Stars and Planets* lesson plans incorporate many of the appropriate NSES assessment, teaching, and professional development standards as part of its written materials and associated educator workshops.

Special attention has been paid to the Project 2061 *Benchmarks for Science Literacy* during the development of *Stars and Planets*. The abilities and background knowledge of middle school students will be kept in mind at all times. When dealing with conceptually challenging topics such the fate of atoms in the formation of neutron stars, the recommendation of the *Benchmarks* regarding student comprehension will be carefully applied in the creation of both student and teacher background materials.

Relevance of State Standards: State standards differ from the National standards in several respects. In Texas, California, and many other states, middle school rather than high school is where students are expected to learn the majority of Earth and space science topics. Therefore, topics such as the nature of stars that are in the NSES content standards for grades 9-12 are relevant to the 6-8th grade content standards for these states. Specific examples include:

1. ***Texas Essential Knowledge and Skills*** for 6th and 8th grade science:
    - 6.13 A) identify characteristics of objects in our solar system including the Sun, planets, meteorites, comets, asteroids, and moons;
    - 8.13.A) Students can "describe characteristics of the universe such as stars and galaxies";
    - 8.13.B) Students can "explain the use of light years to describe distances in the universe".
2. ***Content Standards for California Public Schools***, 8th grade science:
    - 4b) Students know "the sun is one of many stars in our own Milky Way galaxy. Stars may differ in size, temperature, and color;"
    - 4c.) Students know "how to use astronomical units and light years as measures of distance between the sun, stars, and Earth;"
    - 4d) Students know "stars are the source of light for all bright objects in outer space. The moon and planets shine by reflected sunlight, not by their own light."

The development plan for *Stars and Planets* has been specifically designed with the needs of these states, and other states with similar requirements, in mind. As a result, there is a much stronger match between the *Stars and Planets* lessons and many state Earth and space science content standards for middle school than there is with the National Science Education Earth and Space Science Content Standards for the same grade range.

Materials List by Activity

Scale Model Solar System

Materials for Part 1:

- Index cards (9 per student or small group of students) or planet cards
- Markers
- Transparent tape
- Metric rulers
- A copy of the **Size table** (with or without all of the columns filled in) and the student instruction sheet for each student or group of students
- A large grapefruit or approximately 14 cm yellow ball for the Sun for each scale model solar system
- Objects for the planets. Suggestions:
  - poppy seeds or other tiny dark seeds (Mercury, Mars, Pluto)
  - small round candy sprinkles (Venus, Earth)
  - peppercorns or unpopped popcorn – may be dyed blue (Uranus, Neptune)
  - Small Marbles (Jupiter, Saturn)
    - Consider also having some objects such as cherries or small balls that are significantly larger than size a typical marble and smaller than the grapefruit/yellow ball, which are too large to represent the planets on this scale.

Materials for Part 2:

- Labeled cards with objects from Part 1
- Masking tape
- Meter stick(s)
- An open area or straight hallway at least 80 meters (87 yards) long. This is a bit less than the length of a football field.
- A copy of the **Distance** table (with or without all of the columns filled in) and the student instruction sheet for each student or group of students
- **Scale Sun** handout to use for the sun
- Optional: Cones, sticks, or other card holders to hold each of the planet cards as you and your students make your scale model solar system(s).
- Optional: string to attach each of the planet cards together at the proper distances.

Sizes of Stars

Materials:
- **Star Size** Table (1 per student)
- A metric ruler for every student or small group of students

Recommended objects that represent stars and the Earth:
- A three cm (~1 inch) cherry tomato or small red ball (like from a paddle ball or cat toys)
- An orange
- A large grapefruit or 14 cm diameter yellow ball
- A cantaloupe
- A volleyball
- A very large blue play ball (diameter of about 43 cm or 17 inches)
- A picture of blue or violet small roundish car, such as a VW bug (optional)
- a blue candy sprinkle or Earth's planet card from the Scale Model Solar System Activity
- 1 marble or Jupiter card from the Scale Model Solar System

Stellar Distances

Materials:
- A copy of the student instruction sheet for each student
- An orange (for Alpha Centauri B)*
- Two grapefruits (for the Sun and Alpha Centauri A)*
- a cherry tomato or small (3 cm or about 1") red ball*
- A meter stick
- A map of your state, region, or province per group of 3-5 students (The maps need not be identical; the students can bring them from home.)
- At least one globe or map of the world, (One for each group of 3-5 students is preferred.)
- A calculator for each student (optional)

**Or objects of a similar size and color. Use the same objects as in the Sizes of Stars activity.*

Star Birth

Materials:
- A student information sheet for each student
- An experiment worksheet sheet for each student

- A color image of the **Orion Nebula** or internet access for each student or group of 2-3 students
- A copy of the **Relative Numbers of Stars Born by Class** table for each student and/or a copy of this table on a transparency
- 61 small colored objects identical in shape, size, and texture such as plastic beads (inexpensive and easily found in craft stores) for each group of two or three students. Preferred colors and quantities are 50 red, 10 yellow, 1 blue.
- An opaque container to hold the colored objects for each group of two or three students (must be significantly bigger than the 61 objects, and should either have a lid or be shaped such that a student's hand can fit tightly over the opening. **A disposable coffee cup with lid works well.)**
- Scratch paper for each student

Lifetimes of Stars

Materials:

- A copy of the **Stellar Lifetimes Table** for each student
- A copy of the **Major Events on the History of the Earth** table
- A copy of the student instruction sheet for each student
- **Lifetimes of Stars Timeline** copies or Sheets of 8 1/2" x 11" paper *
- A ruler *
- A pair of scissors *
- Pencil*
- Markers or colored pencils (recommended)

  **For each student or small groups of students*

Death of Stars

Materials Required:

- A copy of the student instruction sheet for each student
- **Size table** from the Scale Model Solar System activity
- **Distance table** from the Scale Model Solar System activity

Materials Recommended *(objects that represent the present-day Sun and the Earth)*:

- Large grapefruit or 14 cm yellow ball to represent the present-day Sun
- A cherry tomato or small red ball that is about 3 cm (~1 inch) in diameter to represent a main sequence M class star)
- A blue candy sprinkle or planet card for the Earth from the Scale Model Solar System activity
- A white candy sprinkle glued on black construction paper
- A metric ruler for every student or small group of students

Planet Hunting

Materials for Part 1:

- A copy of the student handout for part 1 for each student
- A blue candy sprinkle taped to a black card or piece of construction paper
- A white candy sprinkle taped to black card or piece of construction paper.
- A candy sprinkle taped to the end of a toothpick
- A shadeless lamp and 100-Watt clear (unfrosted) light bulb
- One large grapefruit or 14 cm yellow ball (for the Sun)*
- A map of the United States, map of the world, or globe
- A calculator for each student*

** Optional, but highly recommended. Objects should be the same or similar to those used in the Scale Model Solar System and Sizes of Stars activities.*

Materials for Part 2:

- A copy of the student handout for part 2 for each student
- A copy of **Table 2: A Sampling of Extrasolar Planets** (with or without all of the columns filled in)
- Three small marbles (to represent Jupiter-like planets)
- Three peppercorns or corn kernels (to represent Neptune-like planets)*
- Two candy sprinkles taped to cards (to represent Earth-like planets)
- One large grapefruit or 14 cm yellow ball (for a Sun-like Star)*
- One orange (for a K class star)*
- One cherry tomoato or small red ball (for a M class star)*
- One cantaloupe (for a F class star)*
- A calculator for each student*

*Objects should be the same or similar to those used in the Scale Model Solar System and Sizes of Stars activities.

Gaggle of Galaxies

Materials:

- A student sheet for each student
- One color printout of the **Hubble Ultra Deep Field** for each small group of students
- A balloon for the teacher to use in a demonstration
- A marker (if the balloon is not already marked with a sine wave)

Several of the activities include Web extensions using images from NASA's Great Observatories. Many of the images have also been included on the Stars and Planets CD that can be downloaded to computers with no or limited Web access.

Montage of planets. Not to Scale.

Image credit: NASA/JPL

In this Exploration, find out

- How the sizes of the planets compare to each other?
- How far apart are the planets?
- What is a scale model?
- What is the solar system mainly composed of?

Scale Model Solar System

Teacher's Guide

In this exercise (based on the Colorado Model Solar System), students will create their own scale model solar systems from common materials for the purpose of exploring concepts of size and distance in the solar system.

Updated to include the 2006 decision by the International Astronomical Union to designate eight planets and three initial dwarf planets in the solar system; this activity can also serve as an introduction to the classification of planets and dwarf planets.

Grade Level: 6-8

Time Frame: The activity is broken into 2 sections; each will take approximately 45 minutes to 1 hour to complete, including short introductions and follow-ups. If you choose to include dwarf planets, plan on an additional class period. Allow about 20 minutes for students to make their own calculations converting to both the scaled sizes and distances between the planets, or give such assignments as homework before the activity. If the students will complete the size and distance tables in class and you are concerned about time, consider providing a partially completed table for your students.

Curriculum Standards: The Scale Model Solar System is matched to:

- National Science and Math Education Content Standards for grades 5-8.
- National Math Standards 5-8, and 9-12 (Number Systems)

Purpose: To aid students in understanding the scale of the solar system, in both the sizes of objects in the solar system, and the vast distances between the Sun and planets. Understanding the scale of the solar system is a crucial component in understanding the nature of astronomical objects and the universe in which we live.

Materials for Part 1:

- Index cards (9 per group of students)
- Markers
- Transparent tape
- Metric rulers
- A copy of the size table (with or without all of the columns filled in) and the student instruction sheet for each student or group of students
- A large grapefruit or approx. 5" ball for the Sun for each scale model solar system (A printable 2-D model of the Sun has also been provided.)
- Objects for the planets. Suggestions:
    - poppy seeds or other tiny dark seeds (Mercury, Mars, Pluto)
    - candy sprinkles (Venus, Earth)
    - peppercorns or unpopped popcorn (Uranus, Neptune)
    - marbles or round candies for (Jupiter, Saturn). You can purchase floral craft marbles at craft stores that work well for both size and color.
    - Consider also having some objects such as cherries or small balls (like Super balls) that are significantly larger than a marble and smaller than the large grapefruit, which are too large to represent the planets on this scale.

Materials for Part 2:

- Labeled index cards with objects from Part 1
- Masking tape
- Meter stick(s)
- An open area or straight hallway at least 80 meters (87 yards) long. This is a bit less than the length of a football field.
- A copy of the distance table and the student instruction sheet for each student or group of students
- Cones on which you can place the model Sun and tape planet cards (optional – consider borrowing these from your school gym.)

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

Introduce Scale Factors:

- The **scale factor** for this scale model solar system is **1:10 billion**.
- One good way to talk about scale factors with your students is to discuss maps. You may also want to ask them to name other types of scale models they have seen before (model cars, model rockets, globes, etc.)
- 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 meter in this scale model equals 10 billion meters.

<u>In boxed section top of page 2</u>

Background: Why Use Scale Models?

- *Scientists use models everyday. Models can be conceptual (ex: an atomic nucleus surrounded by orbiting electrons), mathematical (ex: population increase), and scale (ex: model airplanes).*
- *Scale models are a concept that you are already familiar with in the context of model toys (cars, planes, houses, etc.), maps, and globes.*
- *Scale models allow us to explore systems with scales from the microscopic to the astronomical that are beyond the realm of normal human experience.*
- *Scale models of the solar system aid in understanding the relative sizes and distances of objects in the solar system, an important foundation for studying other topics in astronomy.*

Scale models also provide a concrete, hands-on, method of exploring the nature of our solar system in a classroom setting.

Part 1: Scaled Sizes

Key concepts:

- All planets are much smaller than the Sun.
- The Earth is a relatively small planet.

Teacher Instructions:

Provide a selection of objects for the students to choose from to represent the planets.

- If you have fewer than nine types of objects available (plus the object for the model Sun), mention to your students that they can use the same type of object for more than one planet.

- You may wish to also include objects that are too large to represent planets on this scale in the selection you offer the students. Small rubber balls work well as distractors, as do blue marbles.

- Alternatively, have students fill in the size and distance tables as a math assignment (either in class or as homework), and suggest their own objects that can be brought from home, or which you can provide.

1. *Write the name of each planet on an index card. (The Sun doesn't require an index card.)*
    - You may also want to have the students write down facts about each planet on that planet's index card (leaving space for the object that will represent the planet).

2. *Convert the diameters of the Sun and the planets on the SIZE TABLE to the scaled diameter size.*
3. *Using the "scaled diameters" of the Sun and planets from the size table and your ruler, select objects that are approximately the same size as the scaled size for each planet and the Sun.*

    - Have the students calculate out the scaled sizes of objects and/or Earth diameters from the scale factor and real sizes by providing them with the size table with only the real sizes column filled in and the others blank.
    - **To make the calculations easier**, have the students first **convert** the real sizes given in **kilometers to centimeters** by **multiplying by 100,000 cm/km**. Then students will then simply need to **divide the diameter** of each planet **by 10 billion** to obtain the scaled size.
    - **Do the calculation for the size of the scale model Earth for the students as an example.**
    - Make sure that the students understand that the objects need to be close to, but not exactly, the correct size.
    - If you have sufficient classroom time, consider adding the Moon to the card for the Earth. The Moon is 38 mm away from the Earth on this scale, and is about 1/4 the diameter of the Earth (so a poppy seed will work well to represent it.)

4. *Attach the object you have selected for each planet to an index card.*

    - Transparent tape placed over the object works well to attach an object to the index card.

- While students are working, remind them to measure each object selected to see if their choice is reasonable based on the scaled size for each planet in the data table.

5. *Compare the objects you have selected for the Sun and the planets to the object you have selected for the Earth.*

    - This can be used as a follow-up to the scaled sizes portion of the activity.

If you use distracters, go over which objects are reasonable choices to represent each planet with the class, and give the students an opportunity to correct their planet cards. Rubber balls, for example, can be returned to the teacher and replaced with marbles.

Optional: Including Dwarf Planets

Additional data tables, both with and without all of the data filled in are provided for the first objects classified as dwarf planets.

- Ask your students what objects could be used to include these three dwarf planets on the scale model solar system.
- Your students should note that all of the provided objects are too small to use any of the whole objects provided, although half a poppy seed works well for Pluto and Eris. Ceres is so small that a barely-visible speck of dust would make a good object to represent it on the scale model.

Asteroid Belt Interesting Facts:

If all of the asteroids in the asteroid belt, of which Ceres is the largest, were put together into one object, the model of that object in this scale model solar system would not even equal the size half of a poppy seed!

Another way to think about how little material is really in the asteroid belt is to consider it would take at least 1,000 times the total mass of the asteroid belt to equal the mass of the Earth.

Your students are probably aware that Pluto was officially demoted from full planet status in August 2006. But your students probably won't know that the same thing happened to Ceres soon after its discovery in 1801, following the discoveries of many other asteroids in the asteroid belt.

Part 2: Scaled Distances

Key concepts:

- The solar system is mainly empty space.
- The scale of the solar system is immense.
- The small inner planets (Mercury, Venus, Earth, and Mars) are much closer to the Sun than the outer planets.

Before You Begin:

Find a location that is at least **80 m long** where the students **can walk a straight line** from their model Sun. (You will need about ¼ mile to include Neptune, and about 1/3 mile if you want to include Pluto. We recommend you use areas such as long hallways, football practice field, front sidewalk across school parking lot, etc.)

- You can complete the planet walk as a class, have student groups make parallel model solar systems, or have them radiate out from a central point. Consider class management issues and location in deciding which approach to take with your own class(es). Extra adult helpers may be useful if you choose to have students work in small groups.

Prior to beginning this activity with your class, discuss the scale factor of 1:10 billion again. The scale factor is the same for both the sizes of the objects and the distances in the scale model solar system.

- Every step your students take in the scale model is equal to 10 billion steps in the real solar system. For distance in metric units, this means that 10 million km in the model is represented by 1 m in the scale model, as is easy to see in the table of Real and Scaled Distances of the Planets.

Note: All of the distances for the planets are **average** distances from the Sun. The eight planets have fairly circular orbits. For dwarf planets with highly elliptical orbits like Pluto, sometimes the distance will be much shorter (in the case of Pluto, the minimum distance is inside Neptune's orbit) and sometimes much longer.

Teacher Instructions:

1. *Convert the distances from the Sun to the planets on the DISTANCE TABLE to the scaled distance size.*

    - You can give the students a distance table with columns for real distance from the Sun, scaled distance from the Sun, and steps from previous planet already filled out ***or*** you can have the students calculate the scaled distances and steps from the real distances and the scale factor as a math assignment. If time permits, I would recommend the latter.
    - If you require the students to repeat their calculations for each planet, they may find the experience to be tedious. A way to avoid the problem of tedium can be done as a class activity with each group of two or three students working together to calculate the distance between the Sun "their" planet, and the number of one meter steps between "their" planet and the one before it (or the Sun if the chosen planet is Mercury). Each group can then report on their results to the class, and everyone can fill out their tables together.
    - To make the calculations easier, your students can **convert kilometers to meters** by **multiplying by 1000**. The distance of the Earth from the Sun is 150 million kilometers, or 150 billion meters.
    - **Dividing** by the **scale factor of 1 to 10 billion**, the **distance between the model Sun and the model Earth should be 15 meters.**
    - **<u>Note:</u>** some students may find shortcuts that make their calculations easier. These shortcuts are perfectly acceptable.
    - **The version for younger students includes the use of string or yarn that can be attached to each of the planet cards. You may prefer to use this modification with your own students. Then you can hang it up in the room or hallway for later discussions.**

2. *Using a meter stick, practice making a step 1 meter long. Try this a few times until you are comfortable repeating 1 meter steps or very close.*

    - Have students begin the activity by calibrating their steps to meter sticks.

3. *The class will construct our scale model solar system from the scale model Sun to at least as far as Jupiter. <u>How many meters of space do we need for Jupiter? How many to Pluto?</u> (Hint: look at the table of real and scaled distances.)*

    - If there is sufficient space in the location where you will be constructing the model solar systems, you may want to have students continue pacing and laying down cards as far Pluto (or until you run out of space).

- Going to at least Jupiter will allow your students to see the difference in distances between the closely spaced planets in the inner solar system, and the vast distances to the planets in the outer solar system.
- Going out as far as Uranus will be helpful if you will be doing the distance of stars activity.

4. *With your teacher locate a place to make the scale model solar system, place the object representing the scale model Sun at one end.*
5. *Look at the DISTANCE TABLE, and find the column labeled STEPS. The first planet from the Sun is Mercury, and the number of steps is 6. Walk 6 steps (1 meter each) from the model Sun.*
6. *Stop when you reach 6 steps and place the card for Mercury on the ground or taped to a wall at this distance.*

   - If you are outside on a windy day, hold down the cards with small rocks, or tape them to objects like cones.

7. *Look on the DISTANCE TABLE for the number of steps to the next planet. This number of steps is* ***from Mercury to the next planet*** *out from the Sun,* ***not*** *the total number of steps from the Sun to the next planet.*
8. *Walk to the next planet counting the correct number of steps and repeat the procedure you used for Mercury with the index card. Try to keep your path as straight a line as possible.*
9. *Continue counting steps and placing index cards for each planet up to (and including) Jupiter.*

   - When you get to Earth, can have them illustrate the scale distance of the moon also. It is 4 cm from Earth. Listed in the Analysis Questions.

10. *After Jupiter, if room and time allows, continue counting steps and placing cards all the way to Pluto.*

    - If your students are not able to include all of the planets on their distance model, ask them how much farther they would need to walk to include each planet that was left off. Encourage your students to think of neighborhood landmarks that roughly correspond to those distances.

Optional: Adding Dwarf Planets

As with Part 1, additional data tables are provided for the first three dwarf planets classified by the International Astronomical Union. Ask your where on the model Ceres should go. (**Answer:** Between Mars and Jupiter.) Ask them "How much farther past Neptune they would have needed to walk to include Pluto on the model? How much farther to include Eris?" Once again, asking the students to think of landmarks corresponding to these distances will help them visualize adding these objects. You can use a map of the area around your school to facilitate this discussion.

More on Asteroids: Ceres is the largest object in the asteroid belt, and was briefly classified as a planet.

- A common misconception is that the asteroid belt is densely packed with rocky debris**. In fact, on this scale you would need to grind up a fraction of a poppy seed to represent the material in the asteroid belt, and distribute it in a ring between about 30 and 50 meters from the model Sun.**
- Not all asteroids are in the asteroid belt, but a large fraction of them are, and other asteroids are spread even more thinly. Astronomers have found hundreds of thousands of asteroids, but all are tiny compared to a planet. Most asteroids are tens of kilometers across or smaller.
- As your students have discovered if they included dwarf planets in their scale model, even Ceres, the largest object in the asteroid belt, is barely visible on the scale of this Scale Model Solar System. Added together, the asteroids in the asteroid belt have much less material (mass) than any of the planets or the Moon.

More on Pluto: Pluto, recently considered to be a planet, was once thought to be much bigger than it actually is.

- The 2003 discovery of Eris, which is slightly bigger than Pluto, was the primary reason Pluto's status as a planet was re-examined by the International Astronomical Union.
- However, heated debate among astronomers and planetary scientists on the status of Pluto began in 1992 with the discovery of the first (other) Kuiper Belt object.
- By the time Pluto was demoted, more than 1,000 icy objects had been found past the orbit of Pluto.

***Things to think about* (follow-up):** Discuss the following (in italics) with your students. The other information is provided as a supplement for your use:

1. *How does the size of the object for Earth compare to Mars? Jupiter? Sun?*

2. *The Moon in this model is about 4 centimeters (38 millimeters) away from the scale model Earth (and 1/4 the diameter of the scale model Earth).*

   a) *How does this compare to the distances between the Earth and Venus?*

   b) *the Earth and Mars?*

The Moon is about 30 Earth diameters from the Earth.

3. *How do the distances* ***between planets*** *in the real solar system change as they orbit the Sun?*

   The distances between the planets in the scale model solar system are the minimum distances between the planets, since they are all neatly in a line.

4. *Which does the solar system have more of matter (the Sun, planets, asteroids, etc.) or empty space?*

5. *Light takes about 8 minutes to travel from the Sun to the Earth. What is the speed of light? (Speed = distance/time)*

   - Light (including radio) takes about 8 minutes to travel from the Sun to the Earth.
   - The speed of light is 300,000 km/s

   - Light only takes about 1.2 seconds to travel the distance between the Earth and the Moon.

Supplemental Information for your use:

- The version of this activity for upper elementary students discusses the distances from the nearest star to the Sun, Alpha Centauri.
- For secondary school students, there is a separate activity involving the distances between stars.

This activity is based on the *Colorado Scale Model Solar System* at the University of Colorado at Boulder and associated astronomy exercises compiled by Keith Gleason.

Montage of planets. Not to Scale.

Image credit: NASA/JPL

In this Exploration, find out

- How the sizes of the planets compare to each other?
- How far apart are the planets?
- What is a scale model?
- What is the solar system mainly composed of?

Scale Model Solar System

Purpose:

Today you will make a *scale model* solar system. Every step you take in our model is like walking **10 billion** steps in the real solar system. Our **scale factor** for the model solar system is then **1 to 10 billion** (like the scale on a map). The positions of the model planets are based on each planet's **average distance** from the Sun. The sizes of the planets have the same **scale factor** of 1 to 10 billion as the distances between the planets. It doesn't matter what unit of measure you use. You can use inches, feet, meters, steps, or anything you want.

- *Example:* If you measure the size of the model planets in inches, then multiply your measured number in inches by 10 billion, and you'll get the real size of the planet in inches!

For our scale model solar system, we will use *millimeters, meters,* and *steps* as the **units.**

Materials:

Size of Sun and Planets Table
Diameter of Sun and Planets Table
Various household objects to represent the Sun and planets
Meter stick
Ruler

Part 1: Scaled Sizes

1. Write the name of each planet on an index card. (The Sun doesn't require an index card.)
2. Convert the diameters of the Sun and the planets on the SIZE TABLE to the scaled diameter size.

Background: Why Use Scale Models?

- Scientists use models everyday. Models can be conceptual (ex: an atomic nucleus surrounded by orbiting electrons), mathematical (ex: population increase), and scale (ex: model airplanes).
- Scale models are a concept that you are already familiar with in the context of model toys (cars, planes, houses, etc.), maps, and globes.
- Scale models allow us to explore systems with scales from the microscopic to the astronomical that are beyond the realm of normal human experience.
- Scale models of the solar system aid in understanding the relative sizes and distances of objects in the solar system, an important foundation for studying other topics in astronomy.

3. Using the “scaled diameters” of the Sun and planets from the size table and your ruler, select objects that are approximately the same size as the scaled size for each planet and the Sun.
4. Attach the object you have selected for each planet to an index card.
5. Compare the objects you have selected for the Sun and the planets to the object you have selected for the Earth.

Part 2: Scaled Distances

Now make a scaled distance solar system using your scaled size Sun and planets objects/cards to illustrate the scale of the entire solar system (size and distance).

1. Convert the distances from the Sun to the planets on the DISTANCE TABLE to the scaled distance size.
2. Using a meter stick, practice making a step 1 meter long. Try this a few times until you are comfortable repeating 1 meter steps or very close.
3. The class will construct our scale model solar system from the scale model Sun to at least as far as Jupiter. How many meters of space do we need for Jupiter? How many to Neptune? *(Hint: look at the table of real and scaled distances.)*
4. With your teacher locate a place to make the scale model solar system, place the object representing the scale model Sun at one end.
5. Look at the DISTANCE TABLE, and find the column labeled STEPS. The first planet from the Sun is Mercury, and the number of steps is 6. Walk 6 steps (about 1 meter each) from the model Sun.
6. Stop when you reach 6 steps and place the card for Mercury on the ground or taped to a wall at this distance.
7. Look on the DISTANCE TABLE for the number of steps to the next planet. This number of steps is **from Mercury to the next planet** out from the Sun, **not** the total number of steps from the Sun to the next planet.
8. Walk to the next planet counting the correct number of steps and repeat the procedure you used for Mercury with the index card. Try to keep your path as straight a line as possible.
9. Continue counting steps and placing index cards for each planet up to (and including) Jupiter.
10. After Jupiter, if room and time allows, continue counting steps and placing cards all the way to Neptune.

Things to think about:

1. How does the size of the object for Earth compare to Mars? Jupiter? Sun?

2. The Moon in this model is about 4 centimeters (38 millimeters) away from the scale model Earth (and 1/4 the diameter of the scale model Earth).

    a) How does this compare to the distances between the Earth and Venus?

    b) the Earth and Mars?

3. How do the distances **between planets** in the real solar system change as they orbit the Sun?

4. Which does the solar system have more of matter (the Sun, planets, asteroids, etc.) or empty space?

5. Light takes about 8 minutes to travel from the Sun to the Earth. What is the speed of light? (Speed = distance/time)

Real and Scaled Sizes of the Sun and Planets

	Real Diameter	Scaled Diameter	Earth Diameters
Sun	1,392,000 km	139.2 mm	109
Mercury	4,878 km	0.5 mm	0.38
Venus	12,104 km	1.2 mm	0.95
Earth	12,756 km	1.3 mm	1
Mars	6,794 km	0.7 mm	0.53
Jupiter	142,796 km	14.3 mm	11
Saturn	120,660 km	12.1 mm	9
Uranus	51,118 km	5.1 mm	4
Neptune	49,523 km	5.0 mm	4

The *scale factor* is 1 to 10 billion. Every millimeter in this scale model solar system represents 10 billion millimeters in the real solar system!

Real and Scaled Distances of the Planets

	Real Distance from the Sun (average)	**Scaled Distance from the Sun** (average)	**Steps, 1 m Each** (from previous planet)
Sun	___	___	___
Mercury	58 million km	6 m	6
Venus	108 million km	11 m	5
Earth	150 million km	15 m	4
Mars	228 million km	23 m	8
Jupiter	778 million km	78 m	55
Saturn	1,427 million km	143 m	65
Uranus	2,871 million km	287 m	144
Neptune	4,497 million km	450 m	163

The *scale factor* is 1 to 10 billion. Every meter in this scale model solar system represents 10 billion meters in the real solar system. Similarly, every step in the scale model solar system represents 10 billion steps in the real solar system!

Real and Scaled Sizes of Dwarf Planets

	Real Diameter	Scaled Diameter	Earth Diameters
Ceres	930 km	0.09 mm	0.07
Pluto	2,300 km	0.23 mm	0.18
Eris	2,400 km	0.24 mm	0.19

The *scale factor* is 1 to 10 billion. Every millimeter in this scale model solar system represents 10 billion millimeters in the real solar system!

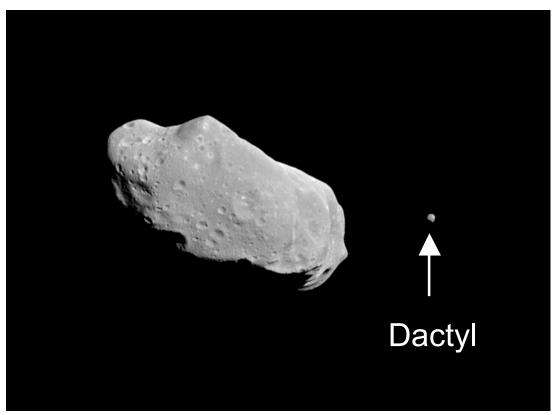
Ceres is the largest object in the asteroid belt between Mars and Jupiter. The asteroid belt is the home of most, but not all, of the rocky asteroids in the solar system. Asteroids we can see from telescopes on Earth are about the size of a mountain or larger.

Pluto and Eris are, as of 2006, the largest known objects in the Kuiper Belt. The Kuiper Belt is filled with icy objects, and is the original home of some comets that visit the inner solar system where they can be seen from Earth.

Did you know? Moons don't make a planet. Pluto and Eris both have moons, but so can much smaller asteroids!

On the right is a picture of the asteroid Ida with its tiny moon, Dactyl. Dactyl is only 1.4 km across!

Image Credit: NASA



* As designated by the International Astronomical Union, the group responsible for classifying and naming objects in the sky, in August 2006. At that time a dozen additional candidate dwarf planets were awaiting official designations.

Real and Scaled Distances of Dwarf Planets*

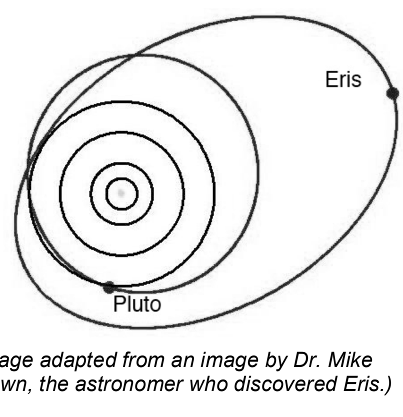
	Real Distance from the Sun (average)	**Scaled Distance from the Model Sun** (average)	**Steps** (at 1 meter each from the model Sun)
Ceres	414 million km	41 m	41
Pluto	5,913 million km	591 m	591
Eris	10,150 million km	1,015 m	1015

The *scale factor* is 1 to 10 billion. Every meter in this scale model solar system represents 10 billion meters in the real solar system. Similarly, every step in the scale model solar system represents 10 billion steps in the real solar system!

Dwarf planets are defined as objects that are massive enough for their own gravity to make them round, and that orbit the Sun (but not another planet), but share their orbits with many similar but smaller objects left over from the formation of the solar system. Most of the rocky debris is in the Asteroid Belt, the home of Ceres. Farther from the Sun is the Kuiper Belt, the home of Pluto and Eris. The icy Kuiper Belt is also the home of many comets.

Did you know? The eight planets all have elliptical orbits, but most are close to perfect circles. Pluto and Eris have orbits that really do look like ellipses.

In the picture on the right, the four circles represent the orbits of Neptune, Uranus, Saturn, and Jupiter. The orbits of the four inner planets, including Earth, are too small to see on the scale of the picture, as is the Sun.



(Image adapted from an image by Dr. Mike Brown, the astronomer who discovered Eris.)

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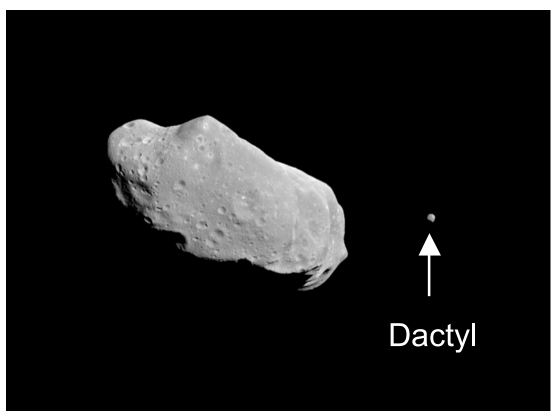

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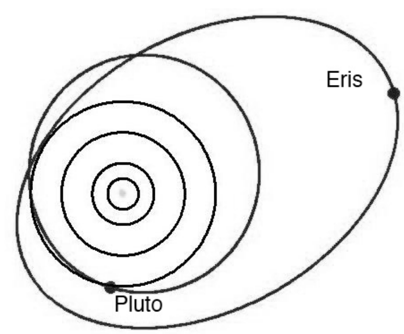

(Image adapted from an image by Dr. Mike Brown, the astronomer who discovered Eris.)

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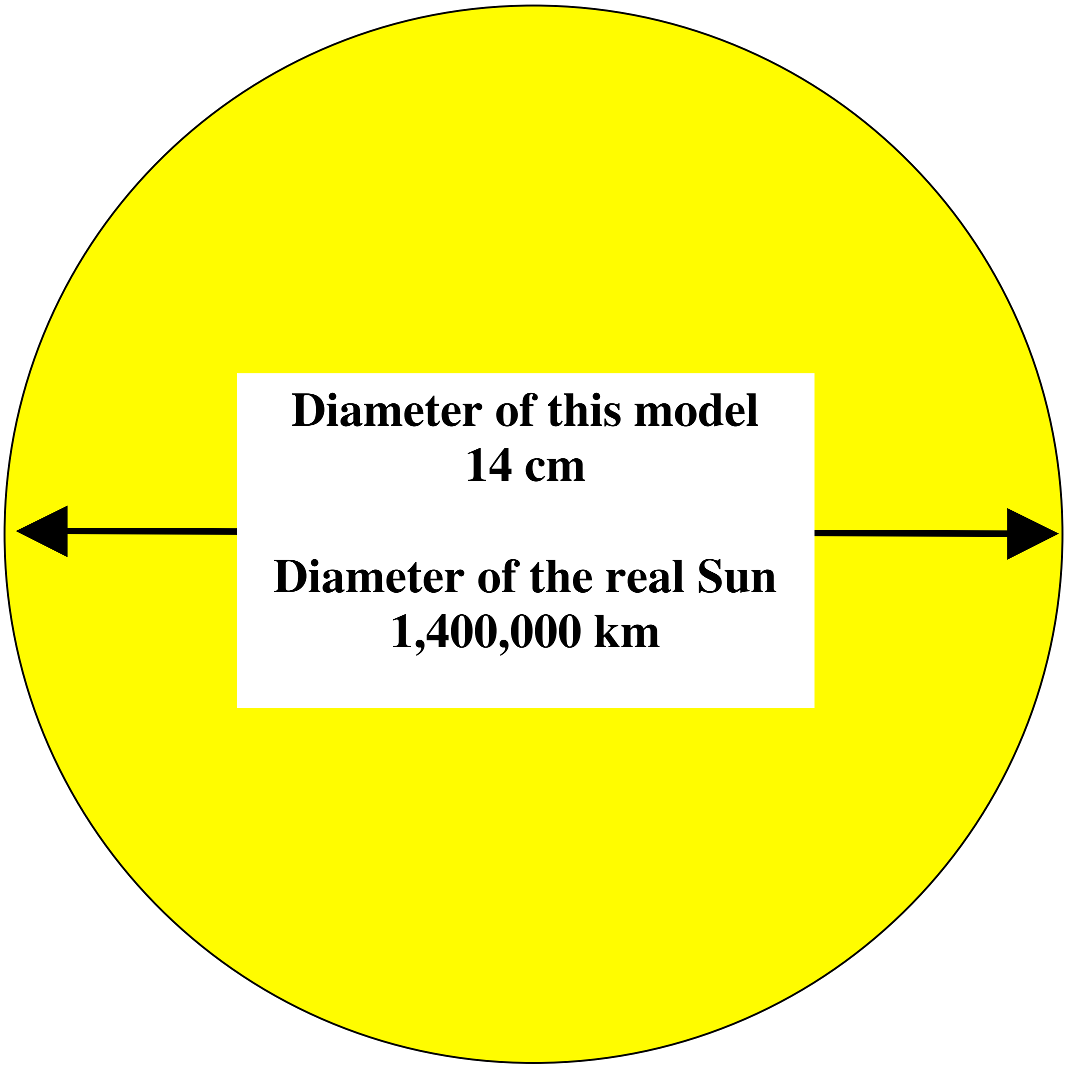
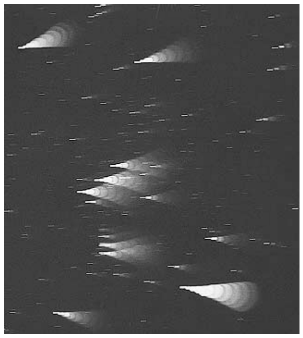
The Sun: Our Star



The real Sun is 10 billion times bigger than this model Sun. Our sun, like all stars, is a very hot ball of gas with a surface temperature of 5,500 °Celsius. At its center the Sun has a temperature of an almost unbelievable 15 million °Celsius.

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.

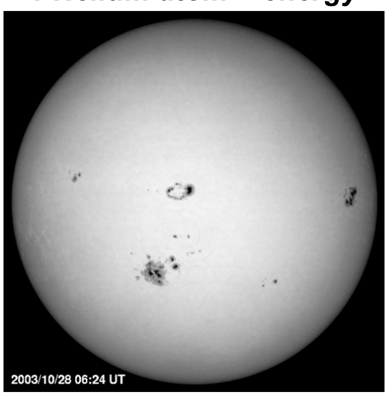
Even though fusion releases a tremendous amount of energy, a lot of heat and pressure is required to make it work. ***Where does the heat inside a star come from initially so that fusion can begin?*** *The answer is* ***gravity****. When a star is forming from the gas and dust particles in space, gravity 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^{o}F) to 40,000 K (70,000^{o}F).*
- *Our own Sun has a surface temperature of 5,800 K (about 10,000^{o}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

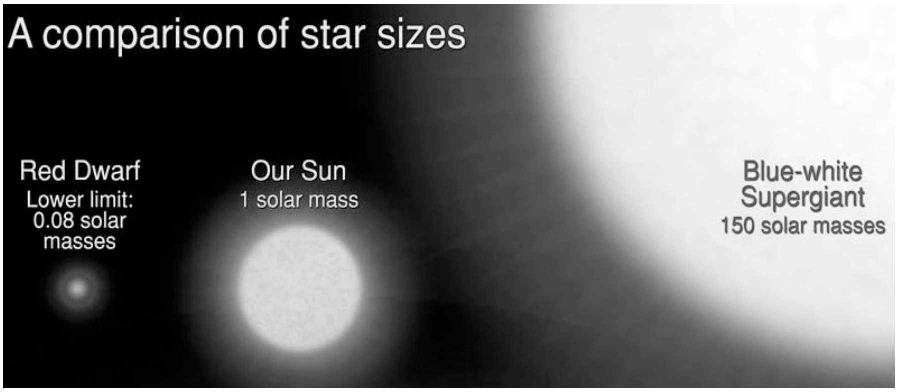
You can see stars of different colors in the night sky. Star colors are easier to see when the sky is very dark. City lights can make it hard to see star colors. You will also need to let your eyes have a chance to adapt to the dark, which usually takes a few minutes. Only very bright stars have visible 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 diameters of stars of different classes are given in the STAR CLASSES Table, along with the mass and color 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 size and color.*
- *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.)*

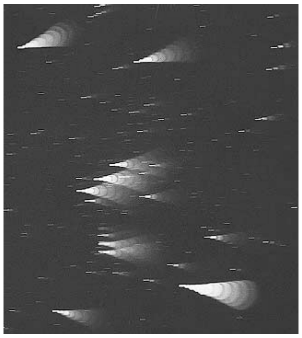
The Sun is 109 times the diameter of the Earth.

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**.

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?

Sizes of Stars

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.

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.**

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.*

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
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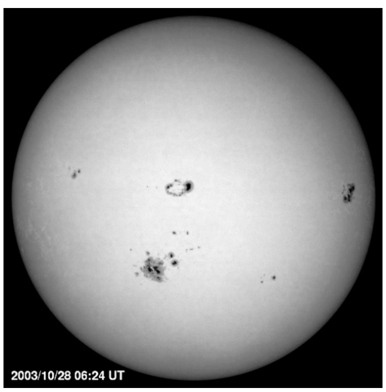

(Image Credit: NASA's Solar Heliospheric Observatory)

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.***

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.**

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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.

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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:

Oh **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?

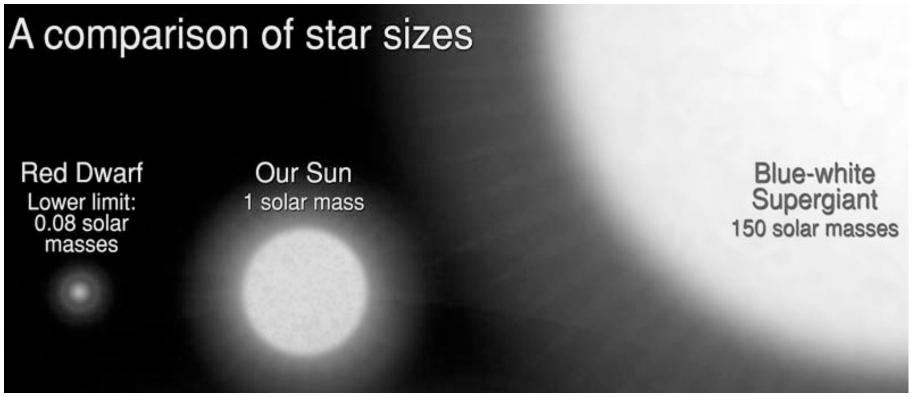
Colors of Stars

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.

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

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 diameters of stars of different classes are given in the STAR CLASSES Table, along with the mass and color 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.

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.

What objects can you think of to represent the stars in our model?

- Try to think of objects that are close to the right size and color.
- 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.)

Discussion Questions:

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

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

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.)

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?

Star Classes

This table gives the star class, color, mass, and size for **main sequence** stars. Most of the real sizes in the table represent a star in the middle of each class. The G class star shown is our sun, which is brighter and larger than the middle of the G class for main sequence stars.

Instructions:
Complete the following size table for classes of main sequence stars using a 1:10 billion scale. Determine a real life object that could be used to represent that star on our scale.

Class	Color	Mass*	Size	Scale Size	Model Object
O	Blue White	40 x M_{Sun}	1300 billion cm		
B	Blue White	6.5 x M_{Sun}	430 billion cm		
A	White	2.1 x M_{Sun}	300 billion cm		
F	Yellow White	1.3 x M_{Sun}	180 billion cm		
G	Yellow	M_{Sun}	140 billion cm	14 cm	
K	Orange	0.7 x M_{Sun}	100 billion cm		
M	Red	0.2 X M_{Sun}	30 billion cm		

*M_{Sun} is the mass of the Sun.
The mass of the Sun is 2,000,000,000,000,000,000 trillion kilograms!

Star Classes

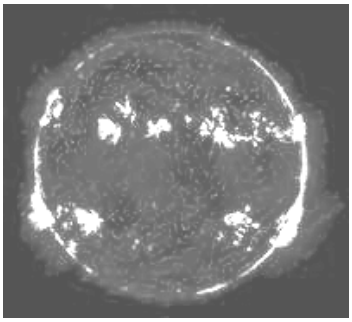
This table gives the star class, color, mass, and size for **main sequence** stars. Most of the real sizes in the table represent a star in the middle of each class. The G class star shown is our sun, which is brighter and larger than the middle of the G class for main sequence stars.

Instructions:
Complete the following size table for classes of main sequence stars using a 1:10 billion scale. Determine a real life object that could be used to represent that star on our scale.

Class	Color	Mass*	Size	Scale Size	Model Object
O	Blue White	40 x M_{Sun}	1300 billion cm	130 cm	Small round car or giant ball
B	Blue White	6.5 x M_{Sun}	430 billion cm	43 cm	large blue play ball
A	White	2.1 x M_{Sun}	300 billion cm	30 cm	volleyball
F	Yellow White	1.3 x M_{Sun}	180 billion cm	18 cm	cantalope
G	Yellow	M_{Sun}	140 billion cm	14 cm	large grapefruit or yellow ball
K	Orange	0.7 x M_{Sun}	100 billion cm	10 cm	orange
M	Red	0.2 X M_{Sun}	30 billion cm	3 cm	cherry tomato or small red ball

*M_{Sun} is the mass of the Sun.
The mass of the Sun is 2,000,000,000,000,000,000 trillion kilograms!

Our Star, the Sun



(Image Credit: NASA/Transition Region & Coronal Explorer)

Note: The above image of the Sun is an X-ray view rather than a visible light image.

In this Exploration, find out:

- *How do the distances of stars compare to our scale model solar system?.*
- *What is a light year?*
- *How long would it take to reach the nearest star to our solar system?*

Stellar Distances Teacher Guide

In this exercise students will plan a scale model to explore the distances between stars, focusing on Alpha Centauri, the system of stars nearest to the Sun. This activity builds upon the activity Sizes of Stars, which should be done first, and upon the Scale in the Solar System activity, which is strongly recommended as a prerequisite. Stellar Distances is a math activity as well as a science activity.

Necessary Prerequisite: Sizes of Stars activity
Recommended Prerequisite: Scale Model Solar System activity

Grade Level: 6-8

Curriculum Standards: The Stellar Distances 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)

Time Frame: The activity should take approximately 45 minutes to 1 hour to complete, including short introductions and follow-ups.

Purpose: To aid students in understanding the distances between stars, how those distances compare with the sizes of stars, and the distances between objects in our own solar system.

Key Concepts:

- Distances between stars are immense compared with the sizes of stars.
- The planets are much closer to the Sun than the next closest star.

Supplies:

- A copy of the student instruction sheet for each student
- 2 large grapefruits or 14 cm yellow balls (for the Sun and Alpha Centauri A)*
- 1 orange (for Alpha Centauri B)*
- 1 cherry tomato or small red ball (3 cm or about 1")*
- A meter stick
- 1 map of your state, region, or province per group of 3-5 students (The maps need not be identical; the students can bring them from home or print maps from the Web.)
- At least one globe or map of the world, (One for each group of 2-4 students is preferred.)
- A calculator for each student (optional)

*Objects should be the same as you used in Sizes of Stars for G,K, and M class stars.

Introduction:

Ask students the following question: Can we include both the Sun and the nearest star to the Sun, Alpha Centauri, on a scale model using the same scale factor we used to model the sizes of stars?

The questions given in the student handout should be attempted by the class one at a time, with an opportunity in between for class discussion and further instructions.

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

Review the Scale Factor:

The scale factor for this scale model is 1:10 billion, and is the same as the scale for the Sizes of Stars and Scale Model Solar System activities in Stars and Planets.

If your students have done both of these activities, simply remind them that the scale factor is the same. If they have done the Sizes of Stars activity, but not the Scale Model Solar System activity, discuss that distance is on the same scale as size was in the previous model.

Every centimeter in the model equals 10 billion real centimeters. Similarly, a kilometer in this scale model equals 10 billion kilometers.

Ask the students how far away they think the nearest star to the Sun would be on a model with a scale factor of 1:10 billion.

Introduce the Nearest Star to the Sun:

Introduce your students to Alpha Centauri, the nearest star to the Sun. Alpha Centauri A triple star system composed of a G class star, a K class star, and a faint M class star, Alpha Centauri is visible from the Southern Hemisphere.

The G class star, Alpha Centauri A, is very much like our Sun, and all three are main sequence stars.

Refer to the chart in the student handout that gives the classes of the three stars and their classes, and ask the students what objects should represent each star. The objects should be the same as those for the G, K, and M class stars in the Sizes of Stars activity. Bring out the objects to represent the stars in the Alpha Centauri system and the Sun, and place them where they can be seen by the entire class. This will aid the students in developing a mental model of the stars in the Alpha Centauri system.

Now that we have modeled the sizes of main sequence stars, we will examine the distances between stars using the same scale factor of 1:10 billion.

Alpha Centauri, the closest star to the Sun, is actually a triple star. Multiple stars are very common. Fifty to seventy-five percent of all stars are in such systems.

Table 1: Distances in the Alpha Centauri System

	Class	***Average Distance from Alpha Centauri A***	***Scaled Distance from Alpha Centauri A***
Alpha Centauri A	*G*	*0 km*	0 km
Alpha Centauri B	*K*	*3 billion km*	3 billion km
Alpha Centauri C	*M*	*1600 billion km*	1600 billion km

What is a Light Year:

A distance of 40,000 billion km or 40 trillion km is almost unimaginably large, and that's just how far it is to the nearest star to the Sun. Using such large numbers to refer to the distances of stars can become awkward very quickly.

*Astronomers use a unit called the **light year** to help deal with this problem.*

A light year is often confused with a measure of time, but is really a measure of distance.

*It is defined as **the distance light can travel in one year. A light year is equal to about 9.5 trillion km or 6 trillion miles.***

The Sun is about 26,000 light years from the center of the galaxy.

Have the students complete Table 1.

The distances given in Table 1 are all from Alpha Centauri A. The stars, however, all orbit the center of mass of the system, which is between Alpha Centauri A and B. Alpha Centauri C, also known as Proxima Centauri, orbits the other two stars. Proxima is also currently the closest star to our Sun.

The image below shows the Sun and the stars in the Alpha Centauri system to scale in size, but not distance.

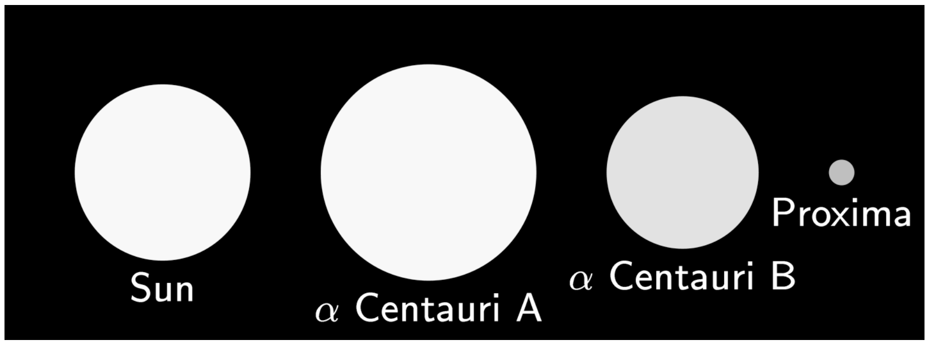


Image credit: David Benbennick, http://en.wikipedia.org/wiki/Image:Alpha_Centauri_relative_sizes.png

1. Using the scale factor of 1:10 billion, how far away from Alpha Centauri A are the other two stars? Fill in the last column of Table 1.

When the students have completed the calculations, either individually or in small groups, discuss the results.

The distance between Alpha Centauri A and B is almost the same as the distance between the Sun and Uranus in the Scale Model Solar System, or about four times the distance between the Sun and Jupiter on the same scale.

Remind the students that the Earth is 15 meters from the Sun on this scale. If the students haven't done the Scale Model Solar System activity, discuss how far the separation of the two stars would be in a model, using familiar landmarks such as your school, and discuss the distance of the Earth from the Sun (150 million km or 93 million miles), which is 15 meters on the scale model.

If your students don't use metric units on a regular basis, converting kilometers to miles or meters to feet might help them to understand the distances in the model. A mile is equal to about 1.6 kilometers, and a meter is equal to about 3.3 feet, so the distance between Alpha Centauri A and B is roughly 1000 ft.

Maps of your state, region, or province will help in discussing distance of Proxima Centauri in the model, which is 160 km or 100 miles away from the other two stars. Separate your students into groups of two - four students. Have each group of students look at a map and suggest a location that is about the right distance from your town for Proxima Centauri on the model.

You may wish to point out to the students that a map is a scale model, too.

2. *How does the choice of Alpha Centauri A as the star from which the other distances are measured affect the distance for Alpha Centauri C, otherwise known as Proxima Centauri?*

Hopefully, your students will recognize that because two larger stars of the Alpha Centauri system are so close together in comparison with the distance to Proxima Centauri, it really doesn't matter which star is chosen.

An analogy might help if any of your students are confused by why the choice of Alpha Centauri A or B doesn't really matter; talk about how distances are measured between towns. If your friend lives a few blocks away, the distance to the next town or city from your house or your friend's house can be treated as the same because that distance is much larger than the separation between the two houses.

The Distances Between the Sun and the Nearest Stars:

Your students may already be surprised by the distances between Alpha Centauri A, B, and the tiny red star, Proxima Centauri. Now, they will discover that the distance between that that distance is tiny in comparison with the distance between Alpha Centauri and the Sun.

The distance between the Sun and the Alpha Centauri System is 40,000 billion km.

3. *How far away would the Sun be from Alpha Centauri on our scale model?*

The Sun and Alpha Centauri are about 4,000 km (or 2,500 miles) apart on this scale model. This is about the distance between San Francisco and New York, or the width of the continental United States.

4. *Where would you place the Sun on the scale model if Alpha Centauri A is at your school?*

A globe or world map works well for this portion of the activity. If each group of students has a globe, ask the students to take a few minutes to choose one or more locations to put the Sun on the model.

Query one or more groups for their locations, and ask the rest of the class if they agree or disagree with the choice(s) of the selected group(s). Two groups of students can share a globe or map, if necessary.

If you only have one globe or map for your classroom, you might wish to consider doing this part of the activity with the entire class. A student volunteer can measure out 4,000 km or 2,500 miles using the scale bar on the globe/map, and choose a location for the class. Pass the globe/map on to a second student volunteer to see if he or she agrees or disagrees with the choice of the other student.

Introduce the Light Year:

Distances to astronomical objects outside of our solar system are usually given in terms of light years. The light year is discussed in the text box on the 2nd page of the student handout.

A distance of 40,000 billion km or 40 trillion km is almost unimaginably large, and that's just to the nearest star to the Sun. Using such large numbers to refer to the distances of stars can become awkward very quickly. Astronomers use a unit called the **light year** to help deal with this problem. A light year is often confused with a measure of time, but is really a measure of distance. It is defined as the distance light can travel in one year, and is equal to about 9.5 trillion km or 6 trillion miles.

A possible analogy to use with your students to help them understand that the light year is a measure of distance is a trip in an automobile. If a car is on the highway and traveling at a constant 65 mph, then 65 miles would be equal to a highway "car hour". The speed of light is a constant 300,000 km/sec.

Table 2: The Twelve Nearest Star Systems to the Sun

Name	***Number of Stars***	***Class***	***Distance from the Sun***
Alpha Centauri	*3*	*G K M*	*4.3 light years*
Barnard's Star	*1*	*M*	*6.0 light years*
Wolf 359	*1*	*M*	*7.5 light years*
BD+36^{o}2147	*1*	*M*	*8.2 light years*
L726-8	*2*	*M M*	*8.8 light years*
Sirius	*2*	*A white dwarf**	*9.5 light years*
Ross 154	*1*	*M*	*9.5 light years*
Ross 248	*1*	*M*	*10 light years*
L789-6	*1*	*M*	*10 light years*
eta Eridani	*1*	*K*	*11 light years*
Ross 128	*1*	*M*	*11 light years*
61 Cygni	*2*	*K K*	*11 light years*

** A white dwarf is a very small, hot star that is no longer on the main sequence*

A star 11 light years from the Sun is more than 100 trillion km away, or 10,000 km away on our scale model!

Sirius, also known as the Dog Star, is the brightest star in sky. It is a hot, bright, A class star with a small companion. However, most of the stars in Table 2 aren't very bright in our sky because they are small and dim M class stars. Ancient astronomers didn't name them, so they were given designations like BD+36^{o}2147 by modern astronomers.

Elaborate - *Traveling to the Stars:*

The following problems may be quite challenging for your students. You may wish to consider having the students work in their small groups to try and solve the problems. You might also give the three problems as homework to more advanced students, or doing the calculations with the entire class.

How long would it take for a spacecraft to reach the nearest star?

We know it will take longer than 4.3 years, because nothing travels faster than light. Let's start by looking at how long it took spacecraft to reach objects in our solar system.

The Apollo spacecraft took about three days to travel the 384,000 km between the Earth and the Moon.

5. *If you are an astronaut sent in a spacecraft traveling at the same speed to Alpha Centauri, how many years would it take you to get there? Would you arrive in your lifetime? Remember: Alpha Centauri is 40 trillion (40,000,000,000,000) km away from the Sun. Hint: How far would you travel in one year?*

Rather than using the concept of significant figures, students in grades 6-8 can make this problem easier by using approximations.

384,000 km / 3 days = 128,000 km/day

128,000 km/day * 365 days/year = 46,720,000 km/year, or about 47 million km/year

40,000,000,000,000 km / 47,000,000 km/year = about 850,000 years

Or, to make the problem even easier,

40 trillion km = 40,000,000 million km

so, 40,000,000 million km / 47 million km/year = about 850,000 years

It will take about 850,000 years to reach the nearest star to the Sun, which is definitely longer than a lifetime. If you think your students will have difficulty with this problem as written, try giving them the distance the spacecraft will travel in a year, and let them work out the remainder of the problem on their own.

What if you sent a robotic spacecraft in your place?

Voyager 1 and Voyager 2 are robotic spacecraft that are currently traveling towards interstellar space. Voyager 1, the faster of the two spacecraft, is traveling at a speed of 540 million km per year.

6. *If you sent a spacecraft that travels at the same speed as Voyager 1 to Alpha Centauri, how long would it take to get there?*

40,000,000,000,000 km / 540,000,000 km/year = about 74,000 years

Or

40,000,000 million km / 540 million km = 74,000 years

NASA launched New Horizons in January 2006 to study Pluto and the Kuiper Belt. At launch, New Horizons was the fastest spacecraft yet built, flying the distance between the Earth and Moon in just 9 hours. On February 28, 2007, New Horizons flew by Jupiter, increasing the speed of the spacecraft to about 72,000 kilometers per hour (45,000 miles per hour).

7. *If New Horizons were on its way to Alpha Centauri instead, how long would it continue into space at this rate? How long would take to get to Alpha Centauri at its current speed?*

72,000 km / hr x 24 hr/day = 1,728,000 km/day

1,728,000 km/day * 365 days/year = 630,720,000 km/year

or about 630 million km/year

40,000,000 million km / 630 million km = about 63,000 years

Follow-up:

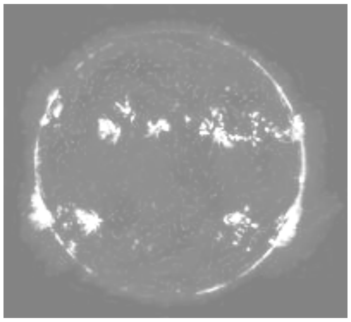
Discuss the distances of the planets from the Sun in comparison with the distances between stars. Earth, as discussed earlier, is only 15 meters from the Sun on this scale model. Compared with the size of the model Earth, this distance is immense, but it is nothing compared with the distance between the stars. This is true even for the most distant planet in our solar system, Neptune, and the dwarf planet, Pluto. The average distance of Pluto from the Sun is about six billion km, or about 600 m (about 1/3 mile) from the Sun on a 1:10 billion scale.

Ask your students why no spacecraft have ever been sent to another star.

Have your students imagine that they are trying to observe their model Sun, a grapefruit, in the very distant location they have chosen for it.

Would they expect to be able to see such a tiny object so far away? Explain to the students that the reason we can see the stars is simply because they are so very bright.

Our Star, the Sun



In this Exploration, find out:

- How do the distances of stars compare to our scale model solar system?
- What is a light year?
- How long would it take to reach the nearest star to our solar system?

Stellar Distances

Now that we have modeled the sizes of main sequence stars, we will examine the distances between stars using the same scale factor of 1:10 billion.

Alpha Centauri, the closest star to the Sun, is actually a triple star. Multiple stars are very common. Fifty to seventy-five percent of all stars are in such systems.

Table 1: Distances in the Alpha Centauri System

	Class	Average Distance from Alpha Centauri A	Scaled Distance from Alpha Centauri A
Alpha Centauri A	G	0 km	
Alpha Centauri B	K	3 billion km	
Alpha Centauri C	M	1600 billion km	

What is a Light Year:

A distance of 40,000 billion km or 40 trillion km is almost unimaginably large, and that's just how far it is to the nearest star to the Sun. Using such large numbers to refer to the distances of stars can become awkward very quickly.

Astronomers use a unit called the ***light year*** *to help deal with this problem.*

A light year is often confused with a measure of time, but is really a measure of distance.

It is defined as ***the distance light can travel in one year. A light year is equal to about 9.5 trillion km or 6 trillion miles.***

The Sun is about 26,000 light years from the center of the galaxy.

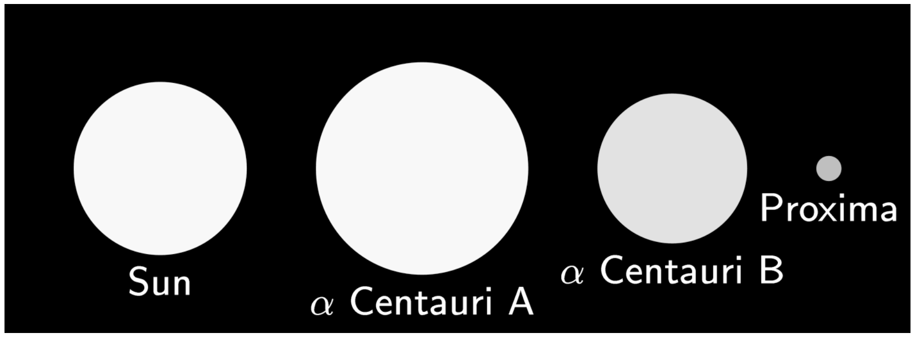


Image credit: David Benbennick, http://en.wikipedia.org/wiki/Image:Alpha_Centauri_relative_sizes.png

1. Using the scale factor of 1:10 billion, how far away from Alpha Centauri A are the other two stars? Fill in the last column of Table 1.

2. How does the choice of Alpha Centauri A as the star from which the other distances are measured affect the distance for *Alpha Centauri C*, otherwise known as *Proxima Centauri*?

The Distances Between the Sun and the Nearest Stars:

The distance between the Sun and the Alpha Centauri System is 40,000 billion km.

3. How far away would the Sun be from Alpha Centauri on our scale model?

4. Where would you place the Sun on the scale model if Alpha Centauri A is at your school?

Table 2: The Twelve Nearest Star Systems to the Sun

Name	Number of Stars	Class	Distance from the Sun
Alpha Centauri	3	G K M	4.3 light years
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* A white dwarf is a very small, hot star that is no longer on the main sequence

A star 11 light years from the Sun is more than 100 trillion km away, or 10,000 km away on our scale model!

Sirius, also known as the Dog Star, is the brightest star in sky. It is a hot, bright, A class star with a small companion. However, most of the stars in Table 2 aren't very bright in our sky because they are small and dim M class stars. Ancient astronomers didn't name them, so they were given designations like BD+36^{o}2147 by modern astronomers.

Traveling to the Stars:

How long would it take for a spacecraft to reach the nearest star?

We know it will take longer than 4.3 years, because nothing travels faster than light. Let's start by looking at how long it took spacecraft to reach objects in our solar system.

The Apollo spacecraft took about three days to travel the 384,000 km between the Earth and the Moon.

5. If you are an astronaut sent in a spacecraft traveling at the same speed to Alpha Centauri, how many years would it take you to get there? Would you arrive in your lifetime? Remember: Alpha Centauri is 40 trillion (40,000,000,000,000) km away from the Sun. <u>Hint: How far would you travel in one year?</u>

What if you sent a robotic spacecraft in your place?

Voyager 1 and Voyager 2 are robotic spacecraft that are currently traveling towards interstellar space. Voyager 1, the faster of the two spacecraft, is traveling at a speed of 540 million km per year.

6. If you sent a spacecraft that travels at the same speed as Voyager 1 to Alpha Centauri, how long would it take to get there?

NASA launched New Horizons in January 2006 to study Pluto and the Kuiper Belt. At launch, New Horizons was the fastest spacecraft yet built, flying the distance between the Earth and Moon in just 9 hours. On February 28, 2007, New Horizons flew by Jupiter, increasing the speed of the spacecraft to about 71,800 kilometers per hour (45,000 miles per hour).

7. If New Horizons were on its way to Alpha Centauri instead, how long would it continue into space at this rate? How long would take to get to Alpha Centauri at its current speed?

Orion Nebula

(Image Credit: HST/NASA)

The central region of the Orion Nebula is shown in an image from the Hubble Space Telescope. What do you see in this image?

In this Exploration, find out:

- *What is a nebula? Interstellar Cloud?*
- *How many stars are born each year?*
- *Which classes of stars are born most often? Which classes are born least often?*

Star Birth Teacher Guide

In this lesson, students will learn about the birth of stars in interstellar clouds of gas and dust. Students will also use an exercise in probability to learn about the relative number of stars of different classes (masses) that are born in a typical stellar nursery. This activity further explores the classes of main sequence stars introduced in the lessons Sizes of Stars and Stellar Distances.

Recommend Prerequisites: Sizes of Stars, Stellar Distances

Grade Level: 6-8

Curriculum Standards: The Star Birth 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)
-

Time Frame: The activity should take approximately 45 minutes to 1 hour to complete, including a short introduction and follow-up. The extension may require an additional class period.

Purpose: To aid students in understanding how stars are born, the relative numbers of stars of different masses born in interstellar clouds, and the lifetimes of stars.

Key concepts:

- Stars are different ages.
- Stars are born in giant clouds of gas and dust called interstellar clouds, which when glowing are also a type of nebula and can be called stellar nurseries.
- Many more low mass (cool) stars are born than high mass (hot) stars.

Supplies:

- A student information sheet for each student or small group of students.
- A Star Birth activity sheet for each student or small group of students.
- A color image of the Orion Nebula (Color Plate 1) or internet access for each student or group of 2-3 students
- A copy of the table of Relative Numbers of Stars Born by Class for each student and/or a copy of this table on a transparency
- 61 small colored objects identical in shape, size, and texture such as plastic pony beads (inexpensive and easily found in craft stores) for each group of two - three students. Preferred colors and quantities are 50 red, 10 yellow, one blue.
- 1 opaque container to hold the colored objects for each group of two - three students (The container must be significantly bigger than the 61 objects, and should either have a lid or be shaped such that a student's hand can fit tightly over the opening. **A disposable coffee cup with lid works well and keeps the noise of a class full of shaking cups manageable.)**
- Scratch paper for each student

Introduction:

Begin with a class discussion, first reviewing terms from the previous activities.

Light Year: Ask your students to define a light year in their own words, or introduce the concept of a light year. (From the activity Stellar Distances: “Distances to astronomical objects outside of our solar system are usually given in terms of light years. A light year is often confused with a measure of time, but is really a measure of distance. It is defined as the distance light can travel in one year, and is equal to about 9.5 trillion km or 6 trillion miles.”)

Main sequence star: To refresh the student’s memories, ask: What is a main sequence star? If you have not done the Sizes of Stars activity, define the term **main sequence stars** to your class. Main sequence stars are stars in the main part of their “lives” that get their energy by converting the element hydrogen into the element helium.

Next, ask the students:

- Are all stars the same age?
- Where stars come from?

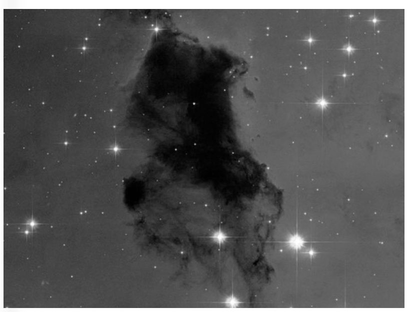
Note: The use of *italics* indicates information or instructions from the student version

Student Reading Materials

You may wish to assign the student reading provided either before or after the activity in class, or use the material as background to aid you in facilitating a class discussion.

*Not all stars are the same age. In our galaxy, the **Milky Way**, a few stars are born every year. Long before stars begin to shine as main sequence stars, the matter they will be made of is spread out in large thin clouds of gas and dust. Lying dark and cold between the stars, these vast **interstellar clouds** are usually only visible to astronomers because they can dim or block out the light of background stars. The atoms, molecules of gas, and tiny bits of dust in interstellar clouds are usually spread very thin. The space between the stars isn't really empty, but the matter in a typical interstellar cloud is spread more thinly than any matter here on the Earth. Interstellar clouds can be tens, or even hundreds, of light years across. Even though they have such a low **density**, these clouds can contain enough matter to make hundreds of thousands of stars like the Sun.*

A Nearby Interstellar Cloud



A dark knot of gas and dust in an interstellar cloud 9,500 light years from Earth blocks the light of the stars and stellar nursery behind it. This image shows an area of the sky about 6.5 light years wide.

***(Image Credit:** NASA, ESA, and The Hubble Heritage Team (STScI/AURA))*

*Every single bit of matter in the universe has gravity, including the atoms and dust grains between the stars. Events such as a **supernova** sometimes trigger these low density clouds to begin to collapse under their own gravity. The collapse of an interstellar cloud begins the process of star birth.*

The collapsing cloud fragments separate into smaller pieces (clumps) that will form individual stars or systems of stars. These bits of cloud heat up as they collapse,

The Orion Nebula

(Image Credit: HST/NASA)

Introduce the Image: The image was taken by the Hubble Space Telescope, and shows a small portion of the Orion Nebula. The Orion Nebula is a stellar nursery in the constellation of Orion, and is about 1,500 light years away. The small part of the Orion Nebula shown in this image is about 2.5 light years across.

with the inner portions becoming very hot. Eventually, if the fragments have enough mass, the inner part of the collapsing gas and dust becomes hot and dense enough to start converting hydrogen into helium. And a star is born. When hot new stars begin to shine in these interstellar clouds, the gas becomes energized by the light of the stars and begins to glow. The parts of the cloud nearest to the hot young stars become a type of ***nebula. Nebulae*** *(the plural of* ***nebula****) are simply glowing clouds of interstellar gas and dust. Nebulae that contain many newborn stars are also called stellar nurseries.*

Introduce Plate 1: The Orion Nebula

Show Plate 1 as a projected image, and/or pass out this high-resolution color image of the central portion of the Orion Nebula to each student or small group of students. You can also have the students look at the Plate 1 on computers. The image can be accessed on the Hubble web site at (http://hubblesite.org/newscenter/newsdesk/archive/releases/1995/45/image/a).

Ask the students to look closely at the image. What do they see?

- **Colors:** The nebula is glowing. The primary colors are red and green.

The colors of the nebula tell astronomers what gases the nebula is made of. The green is from hydrogen gas. (This is false color to distinguish it from nitrogen; hydrogen really emits in red).

Hydrogen is the most abundant gas in the nebula, as well as the most abundant element in the universe. The red is from nitrogen gas. Nitrogen is much less abundant in the nebula than hydrogen, but is the primary component of the Earth's atmosphere. The little bit of blue in the image is from oxygen.

- **Stars:** The four bright stars near the center of the Nebula are called Trapezium.

Tarantula Nebula

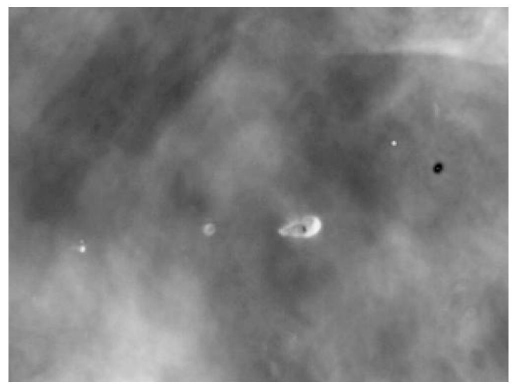
(Image Credit: HST/NASA)

At the center of this Tarantula Nebula is a cluster of stars that make this formation appear very bright when observed from Earth. It is such a bright object in the night sky that it was at first mistaken for a star.

The Tarantula Nebula is so large, that if it were as close to us as the Orion Nebula it would take up half the sky. The Tarantula Nebula is a known as a ***starburst*** *region – that is, an area where an unusually high number of stars are being formed.*

These stars aren't red, as they may appear in the image, but are blue-white O and B class stars. The large amount of gas and dust between the Trapezium stars and the Earth makes them look red, much like the gas and dust in the atmosphere makes the Sun look reddish at sunset or sunrise. Fainter stars are also visible.

- **Stars with tails?** In a high quality image, shapes looking like stars with tails may be visible. If the students can see these features in the image, go ahead and discuss them. Otherwise, they can be discussed in an extension.



The "tails" are actually denser disk-shaped clouds of gas and dust about the size of our solar system (two to eight times the width of the orbit of Pluto) that are encircling individual newborn stars. Astronomers think these objects are planetary systems just starting to form. Four and a half billion years ago, before our planets formed, our own solar system probably looked very similar to these features.

Counting Stars

Ask each student or small group of students to count how many stars they can see in the picture. After a few minutes, the students should have an estimate for how many stars they can see. Query the students on how many stars they could find.

Ask the class if they think they could see all the stars in the region of the nebula seen in the image. If not, what could make stars hard to see? Some possible answers:

- Dust can obscure stars.
- Glowing gas can make stars very hard to see.
- The Orion Nebula is far away.
- The image is too small or does not have high enough resolution to see the stars.

Ask your students: Do you think that stars of some classes will be easier to see than stars of other classes? Why or why not?

High mass stars will be much easier to see than low mass stars, simply because they are much brighter. Cool, red M class stars are so dim they can be difficult to see even in the neighborhood of our solar system.

Tell the students that astronomers have counted more than 700 stars in this portion of the nebula. Compare this number with the estimates from the class.

What Stars are Born?

Ask the students " Do you expect that equal numbers of high mass stars and low mass stars will be born in a typical stellar nursery?"

When they look at stars inside and outside of stellar nurseries, astronomers have found that many more dim, red low mass stars are born than blue-white high mass stars. Whenever a star is born, it has a higher chance, or **probability,** of becoming a low mass star than a high mass star, or even medium-mass yellow star.

Explain to the class that they will do an experiment simulating the birth of stars of different masses (and therefore colors) in a stellar nursery.

Star Birth Activity

Divide the class into small groups of two to three students. Give each group of students a container with the 50 red objects, 10 yellow objects, and one blue object.

If they do not already have them, give each student or small group of students pages 3 & 4 of the student version of Star Birth.

Allow the class a few minutes to answer the pre-experiment questions, either individually or in their small groups.

The experiment itself will take roughly ten minutes, plus a few addition minutes for the making the table and answering the post-experiment questions.

Star Birth Activity

Answer these questions **before** the activity:

1) *If you have 50 red objects, 10 yellow objects, and 1 blue object all mixed up together in a box, what is the probability that an object you take out of the box (without looking) will be blue?*

   Answer: (1/61)

2) *What is the probability it will be red?*

   Answer: (50/61)

3) *What is the probability it will be yellow?*

   Answer: (10/61)

4) *If you put the first object back, mix up the objects in the box, and draw out another object, will the probabilities of drawing out an object of a particular color change or will they be the same?*

   Answer: (1/61)

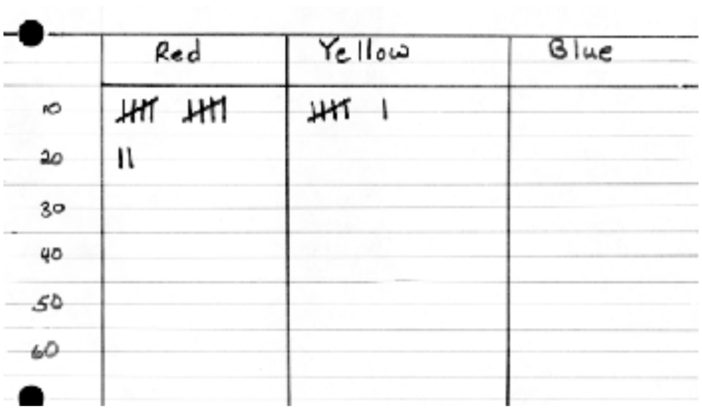
5) *If you draw out an object one at a time, record the color, and put it back before drawing another object, and do this 61 times, how many red, yellow, and blue objects will you expect to draw out? Will this number be exact or approximate? Why?*

   Answer: the numbers will be approximately 50 red, 10 yellow, and one blue, but will vary because the probability of drawing an object of a specific color will not change with each object drawn

   (Only after the experiment has been repeated many times can one expect the average distribution to be 50 red, 10 yellow, and one blue.)

Now, using the 61 colored objects in the container you have been given, you'll have a chance to see if your prediction is correct. Before you start, your group should make a table on a separate piece of paper with columns for red, yellow, and blue.

Your table might look something like this.



Keep track of the number of objects you have drawn out of each color using tick marks. Grouping tick marks 10 to a line will help you quickly count how many objects you have drawn so far. To help you count quickly, you can put numbers in the margin as shown in this example. Write the names of each of the members of your group on the top of the paper.

Next, shake up the objects in the container, and take one object out without looking.

Now, look at the object, record the color of the object, and put it back.

Repeat this until you have drawn a total of 61 times.

*Answer these questions **after** you finish the activity:*

6) *Total the tick marks in each of the 3 columns. How did you numbers compare with the numbers of objects of each color in the box? Did you get the numbers you expected?*

   Student numbers will probably vary from what they expected. Students typically expect to draw 50 red, 10 yellow, and one blue.

7) *What if you **hadn't** put the first object back? Would your probabilities for drawing out an object of a given color change, or be the same? Why?*

   Answer: Change. With each object drawn, the probability for what the next object would be would change depending on what objects remained in the container. This is called *conditional probability*.

8) *What would the total values in your columns be if you didn't put any of the objects back before drawing out the next object, and drew 61 times?*

   Answer: Exactly 50 red, 10 yellow, and one blue

Follow-up:

Once the class has completed their experiment and their worksheets, discuss the results of the experiment with the class. (You may wish to have the students turn in their worksheets prior to the discussion so that you can use them for evaluation purposes.)

- How did numbers from the different groups compare with one another?
- Were the averaged numbers for the whole class closer to the expected values than most individual group results?

Discuss the observed and predicted relative numbers of stars born in stellar nurseries.

Astronomers call the number of stars born as a function of mass the stellar **initial mass function**, or IMF for short. The IMF also states the probability of a star being born with a particular mass. Even for stellar nurseries relatively close to the Earth, the IMF for our galaxy is really an estimate. Individual stellar nurseries will have different relative numbers of low, medium, and high mass stars. Astronomers have different estimates for the IMF, but in all cases, many more dim red low mass stars are born than medium mass yellow stars like our Sun. Very massive blue-white O stars are rare. One estimate for the IMF is given in Table 1: Relative Numbers of Stars Born by Class, which is also available as a separate student handout.

Table 1: Relative Numbers of Stars Born by Class

Class	Color	Mass / Mass of Sun	Relative Number Born
O	Blue White	40	1
B	Blue White	6.5	40
A	White	2.1	200
F	Pale Yellow to White	1.3	500
G	Yellow	1	900
K	Orange	0.7	7000
M	Red	0.2	200,000

The numbers in Table 1are one estimate of the number of stars of different classes that might be born for every O class star. A few estimates are higher, many are lower, but all have many more low mass stars than high mass stars.

Table 1 is for **main sequence** stars.

Astronomers try to determine the IMF of a stellar nursery using a process similar to the counting of stars the students did near the beginning of the lesson.

Very low mass stars are so dim that many can't be counted. Astronomers must **extrapolate** the numbers of very low mass stars based on the numbers of higher mass stars. Dust and glowing gas can make it very hard to count stars. Sometimes individual stars are so cocooned in gas and dust that visible light can't even escape.

The ongoing effort to determine the IMF of stars in our galaxy and other nearby galaxies is one of many examples of how science is a dynamic field. **Not everything in science can be found in books!**

Extension:

If you have Internet access available for small groups of students, or the resources to make several good quality printouts for each small group, consider having the students examine other star forming regions.

The Hubble Space Telescope website (hubblesite.org) has fabulous images of stellar nurseries other than the Orion Nebula, along with captions containing a great deal of useful information. To further extend your investigations into the infrared part of the electromagnetic spectrum, visit the Spitzer Space Telescope website (http://www.spitzer.caltech.edu/),

Some good examples for your students are:

Eagle Nebula (http://hubblesite.org/newscenter/newsdesk/archive/releases/1995/44/)

Trifid Nebula (http://hubblesite.org/newscenter/newsdesk/archive/releases/1999/42/)

A closer look at the Orion Nebula shows disks of gas and dust around young stars believed to be forming planetary systems.

http://hubblesite.org/newscenter/newsdesk/archive/releases/1994/24/image/b

http://hubblesite.org/newscenter/newsdesk/archive/releases/1994/24/image/c

See the Orion Nebula's gas and dust gas reflecting the light of a bright young star.

http://hubblesite.org/newscenter/newsdesk/archive/releases/2000/10/image/a

And to glimpse star formation beyond our own galaxy in the nearby Large Magellanic Cloud (a satellite galaxy of the Milky Way):

30 Doradus Nebula
(http://hubblesite.org/newscenter/newsdesk/archive/releases/1999/33/)

Tarantula Nebula
(http://hubblesite.org/newscenter/newsdesk/archive/releases/1999/12/)

Questions to ask the students during, or as a follow-up, to their investigations:

- How are the stellar nurseries different from the Orion Nebula and one another? How are they the same?

- Which stellar nurseries would cause astronomers the most problems counting newborn stars and determining the IMF? Why?

- Can you find cocooned young stars that might be forming planetary systems in any of these images? If so, which ones?

Orion Nebula

(Image Credit: HST/NASA)

The central region of the Orion Nebula is shown in an image from the Hubble Space Telescope. What do you see in this image?

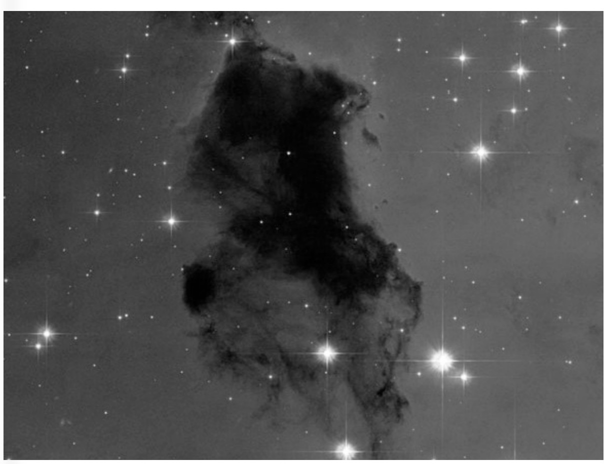
In this Exploration, find out:

- What is a nebula? Interstellar Cloud?
- How many stars are born each year?
- Which classes of stars are born most often? Which classes are born least often?

Star Birth

Not all stars are the same age. In our galaxy, the **Milky Way**, a few stars are born every year. Long before stars begin to shine as main sequence stars, the matter they will be made of is spread out in large thin clouds of gas and dust. Lying dark and cold between the stars, these vast **interstellar clouds** are usually only visible to astronomers because they can dim or block out the light of background stars. The atoms, molecules of gas, and tiny bits of dust in interstellar clouds are usually spread

A Nearby Interstellar Cloud



***(Image Credit:** NASA, ESA, and The Hubble Heritage Team (STScI/AURA))*

A dark knot of gas and dust in an interstellar cloud 9,500 light years from Earth blocks the light of the stars and stellar nursery behind it. This image shows an area of the sky about 6.5 light years wide.

very thin. The space between the stars isn't really empty, but the matter in a typical interstellar cloud is spread more thinly than any matter here on the Earth. Interstellar clouds can be tens, or even hundreds, of light years across. Even though they have

Tarantula Nebula

(Image Credit: HST/NASA)

At the center of this Tarantula Nebula is a cluster of stars that make this formation appear very bright when observed from Earth. It is such a bright object in the night sky that it was at first mistaken for a star.

*The Tarantula Nebula is so large, that if it were as close to us as the Orion Nebula, it would take up half the sky. The Tarantula Nebula is a known as a **starburst** region – that is, an area where an unusually high number of stars are being formed.*

such a low **density**, these clouds can contain enough matter to make hundreds of thousands of stars like the Sun.

Every single bit of matter in the universe has gravity, including the atoms and dust grains between the stars. Events such as a **supernova** sometimes trigger these low density clouds to begin to collapse under their own gravity. The collapse of an interstellar cloud begins the process of star birth.

The collapsing cloud fragments separate into smaller pieces (clumps) that will form individual stars or systems of stars. These bits of cloud heat up as they collapse, with the inner portions becoming very hot. Eventually, if the fragments have enough mass, the inner part of the collapsing gas and dust becomes hot and dense enough to start converting hydrogen into helium. And a star is born. When hot new stars begin to shine in these interstellar clouds, the gas becomes energized by the light of the stars and begins to glow. The parts of the cloud nearest to the hot young stars become a type of **nebula. Nebulae** (the plural of **nebula**) are simply glowing clouds of interstellar gas and dust. Nebulae that contain many new born stars are also called stellar nurseries.

Star Birth Activity

Answer these questions **before** the activity:

1) If you have 50 red objects, 10 yellow objects, and 1 blue object all mixed up together in a box, what is the probability that an object you take out of the box (without looking) will be blue?

2) What is the probability it will be red?

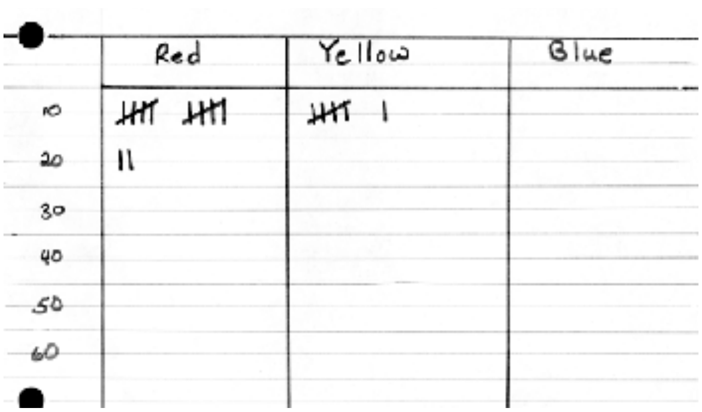
3) What is the probability it will be yellow?

4) If you put the first object back, mix up the objects in the box, and draw out another object, will the probabilities of drawing out an object of a particular color change or will they be the same?

5) If you draw out an object one at a time, record the color, and put it back before drawing another object, and do this 61 times, how many red, yellow, and blue objects will you expect to draw out? Will this number be exact or approximate? Why?

Now, using the 61 colored objects in the container you have been given, you'll have a chance to see if your prediction is correct. Before you start, your group should make a table on a separate piece of paper with columns for red, yellow, and blue.

Your table might look something like this.



Keep track of the number of objects you have drawn out of each color using tick marks. Grouping tick marks 10 to a line will help you quickly count how many objects you have drawn so far. To help you count quickly, you can put numbers in the margin as shown in this example. Write the names of each of the members of your group on the top of the paper.

Next, shake up the objects in the container, and take one object out without looking.

Now, look at the object, record the color of the object, and put it back.

Repeat this until you have drawn a total of 61 times.

Answer these questions **after** you finish the activity:

6) Total the tick marks in each of the 3 columns. How did you numbers compare with the numbers of objects of each color in the box? Did you get the numbers you expected?

7) What if you **hadn't** put the first object back? Would your probabilities for drawing out an object of a given color change, or be the same? Why?

8) What would the total values in your columns be if you didn't put any of the objects back before drawing out the next object, and drew 61 times?

Table 1: Relative Numbers of Stars Born by Class

Class	Color	Mass / Mass of Sun	Relative Number Born
O	Blue White	40	1
B	Blue White	6.5	40
A	White	2.1	200
F	Pale Yellow to White	1.3	500
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This table is for **main sequence** stars.

Pleiades Star Cluster

Eventually these "seven sisters" will drift apart.

Image *Credit:* *NASA, ESA and AURA/Caltech*

An open cluster of stars, like the Pleiades, is a group of stars that started together in a stellar nursery.

In this exploration, find out:

- What determines how long a star can live?
- How do lifetimes of other stars compare to our star, the Sun?
- How do lifetimes of stars compare to major events in the history of the Earth?
- Why do the lifetimes of stars matter to astronomers?

Lifetimes of Stars Teacher's Guide

In this exercise, students will make a scale model of time, and compare the lifetimes of different masses of stars both to each other and to the geologic timeline for the Earth. Students will then make predictions about what classes of stars might have planets with interesting (as defined by the students) life forms, assuming that the history of life on Earth is typical.

Recommended Prerequisites: Sizes of Stars and Star Birth

Grade Level: 6-8

Time Frame: The activity will take one to two class periods (45 minutes to one hour each) to complete. To save time, consider having students use the pre-made timeline template.

Curriculum Standards: The Lifetimes 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 aid students in understanding the wide variation in the ages of stars and how the lifetime of a star depends upon its mass. Students will also learn how the lifetimes of stars relates to the reason stars of a certain mass range are the focus of searches for Earth-like planets beyond the solar system.

Key Concepts:

- How long a star shines is very dependent on its mass.
- Low mass stars have less hydrogen to convert to helium than do high mass stars, but live much longer.
- Our sun has lived about half of its "life" as a main sequence star (fusing hydrogen into helium in its core).
- For most of the history of the Earth (and the Sun), bacteria and other microorganisms were the only forms of life on our planet.
- The lifetimes of stars are relevant to the search for life on planets outside our solar system.

Required Supplies:

- A copy of the Stellar Lifetimes Table for each student
- A copy of the Table of Major Events on the History of the Earth
- A copy of the student instruction sheet for each student
- Nine sheets of 8 1/2" x 11" paper or timeline*
- A ruler *
- A pair of scissors *
- Tape*
- Pencil*
- Colored pencils or markers

*For each student or small groups of students

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

Introduction:

Begin by asking the class a few questions about the lifetimes of stars, and discuss the answers the students give.

- How long do stars shine? Note: you may need to review why stars shine, discussed in the activity Sizes of Stars.
- How long do they stay on the main sequence (converting hydrogen to helium as their energy source)? How old is the Sun?
- How much longer will the Sun stay a main sequence star?
- Do stars all "live" the same amount of time?
- Which types of stars "live" longer, high mass stars or low mass stars?

After this introductory discussion, give each student a copy of the Student Instruction Sheet and the student version of Table 1: Lifetimes of Stars. Consider having the students read through the explanatory material in class, or alternatively, send the sheet home to be discussed the next class period.

Comparing (Main Sequence) Lifetimes of Stars:

The time stars spend on the main sequence is often called the "lifetime" of stars. Stars will stay on the main sequence until they run out of hydrogen fuel in their cores. When a star runs out of hydrogen fuel, it has begun to die.

> ***Remember: Main Sequence***
>
> *Main sequence of stars is when they are in the main part of their lives, using Hydrogen in their cores*
>
> *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**orilla **K**iss **M**e!*

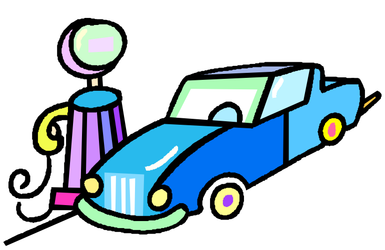
What determines how long a star can live?

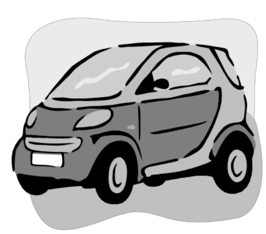
- ### *Available Hydrogen*

How long a star can rely on converting hydrogen to helium for its fuel depends on two main factors. How much hydrogen it has available is one. But how fast the hydrogen is used up in the core of the star is at least as important. Stars are made mostly of hydrogen, but only about 1% of the hydrogen in a star can be converted into helium. That 1% is in the core, where temperatures and pressures are high enough for fusion to take place. A star 40 times the mass of the Sun will have about 40 times as much hydrogen available to convert to helium. Because of this, it would seem to make sense that high mass stars should live longer than low mass stars. But this isn't true.

- ### *Mass, Pressure, and Heat*

The more mass a star has, higher the pressure will be in the core, and the hotter the interior of the star will be. Hydrogen atoms are converted more quickly into helium when pressures and temperatures are higher. The more mass a star has, the faster it will convert its hydrogen fuel into helium. It turns out that high mass stars, even though they have more fuel, use up that fuel much more quickly than low mass stars can. So, low mass stars have much longer lives than high mass stars! It's like the way a gas guzzling car with a big gas tank can run out of gas before a fuel efficient car with a smaller gas tank will.





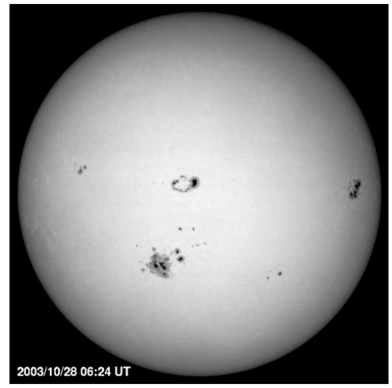
Comparing the Lifetimes of Stars

How do the main sequence lifetimes of stars of different masses compare with one another?

*Take a look at the **Lifetimes of Stars** table (**Table 1**).*

- *How does the lifetime of each mass of star in the table compare with the lifetime of the Sun (the G class star)?*
- *Which stars born at the same time as the Sun have left the main sequence?*

Our Star the Sun



(Image Credit: NASA's Solar Heliospheric Observatory)

The Sun has been a main sequence G class star for about 4.5 billion years, and will stay on the main sequence for another 5 to 6 billion years or so.

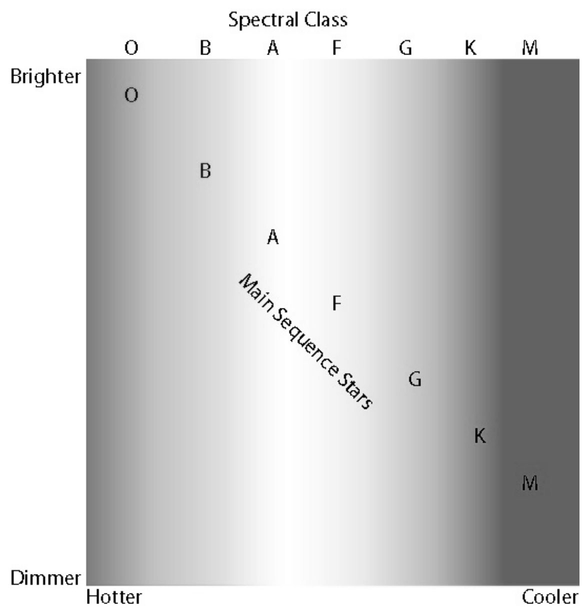
Why do the lifetimes of stars matter to scientists?

Lifetimes of stars matter for several reasons. Short-lived high mass stars often help continue the process of star formation in the same stellar nurseries in which they are born when they become supernovae. Dying high-mass stars also send rock-forming elements into interstellar clouds. These elements can eventually form planets around other, lower mass, stars.

Astronomers are searching for planets around other stars, and have already found many giant planets. NASA is working on ways to find small rocky planets like the Earth around other stars, too. One of the reasons scientists would like to find Earth-like planets, is the hope of finding evidence of life on a world outside the solar system. How long different masses of stars live will affect the chances that a planet around a star will have life, and what type of life it may have.

Hertzsprung - Russell Diagram

The H-R is a diagram illustrating where a star is categorized based on spectral class, temperature, and brightness. Stars on the main sequence make a diagonal line in this diagram.



Remember:

- *Low mass main sequence stars are cooler, and are reddish.*
- *High mass stars main sequence stars are hotter, and are white or blue white.*
- *High mass stars are also much brighter than low mass stars, because they produce much more energy.*

Scale Model of Time Activity:

If you choose to provide your students with the timeline template, the stars are pre-drawn. Students will need to assemble their timelines using many of the same steps described in their handout, but will skip adding the stars. You may also wish to use the template as an example, and have students create their timelines from plain sheets of paper.

Scale models can be used to represent time as well as sizes and distance. In a timeline, distance is used to model time. This scale model of time will be made using a timeline made from nine sheets of paper.

If you are short on time, the Timeline Template, in either color or b&w. Representing the lifetimes of the classes of stars with colored lines is highly recommended. Students can use markers or colored pencils to trace over the

lines representing the lifetimes of stars in the b&w version. For A class stars, black can be used instead of white. F class stars can be represented with a dashed yellow line.

Instructions for making the timeline:

1. *Take 9 sheets of notebook or typing paper. Trim each sheet so that it is 25 cm (just under 10 inches) long.*
2. *Lay two pieces of the trimmed paper down on a desk or table lengthwise so that the edges are touching, but not overlapping.*
3. *Tape the right edge of the first piece to the left edge of the 2nd piece. Now, add another sheet of paper to the first two the same way.*
4. *Repeat until all nine sheets of paper are taped together into one long sheet. Because the sheet will be getting very long, try folding it up like an accordion, bending at the taped edges. When all nine sheets are added, the long sheet should be roughly 2 1/4 meters long (or 9 x 25 cm).*
5. *Now, place the folded "accordion" of paper lengthwise on your desk. Using a ruler, draw a horizontal line 8 cm from the bottom across the entire length of the first page.*
6. *Repeat on the remaining 8 sheets of paper, so that if you unfold your "accordion" you'll have one long line across all 9 pages.*
7. *Next, go back to first page and place a "0" at the far left end of the horizontal line. This "0" represents the time of the formation of the Earth.*

On the timeline, each **sheet of paper** will equal 500 million years and every **centimeter** will equal 20 million years.

Add stars of different classes to the timeline

Next, draw horizontal lines on your timeline for the lifetimes of each of the seven classes of main sequence stars.

- *Start about 12 cm above the bottom of the pages for the first star class.*
- *Add a separate line above the first one for each class of star. Make them about one cm apart.* ***Colored lines matching the color of each class of stars are recommended.***
- *Some star classes will be longer than the span of 4.5 billion years (the total of your pages). In these cases, on the last page use an arrow at the end of the line for that star to indicate a longer life span than is shown on the timeline.*

You are now ready to add events to your timeline.

Give each student, or small group of students, a copy of **Table 2: Some Major Events in the History of the Earth**. The times for the events are given in two different forms: years since the Earth's formation or years ago. The students can therefore measure distance on their timelines from the beginning of the timeline, or from the present, which ever is easier.

Go over the example of how to calculate the distance of an event from both the beginning and the end of the timeline.

Example: *The oldest surviving rocks on the Earth are about 4 billion years old, so they formed about 0.5 billion or 500 million years after the formation of the Earth.*

How far from the beginning of the timeline do we mark this event?

(Time of Event from Beginning of Timeline)/ Scale Factor
= Distance from Beginning of Timeline

so

500 million years / 20 million years per cm = 25 cm
(which also happens to be one sheet of paper).

- *How would this change if you wanted to calculate the distance on your timeline measured from the end of the timeline (the present)?*

Put major events from the history of the Earth on the timeline

Take the events given in the ***Table 2****:* ***Some Major Events in the History of the Earth*** *and mark each of them on them on the timeline. You may use the space both above and below your timeline.*

- *The times of the events in the table are given in both years from Earth's formation and years from the present (how many years ago an event occurred). Both numbers have been provided so that you can easily work from either end of your timeline.*

Comparing Stellar Lifetimes to the History of Life on Earth.

Which classes of stars have shorter lifetimes than the Earth has had so far?

Assume that a star of each class was born at the same time as our own sun. For each class of stars with lifetimes shorter than the age of the Earth, answer these questions:

- *What was the Earth like over the time period that the star would have been on the main sequence?*
- *Did life exist on the Earth before the star died? If so, what type?*

Follow-up:

After each group has completed Table 1, the timeline, and answered the questions in the student handout, discuss with the students how the comparison of the history of life on Earth relates to the search for planets around other stars.

Assuming that the history of life on Earth is typical, what classes of stars do the students think astronomers should focus on?

- What criteria are the students using for their answers?

- Do the students think astronomers should look for stars that could have planets:
  - capable of having bacteria or other microbes,
  - or planets with larger life forms like plants and animals,
  - or just for stars with planets that could have creatures capable of making a civilization?

- What do your students think of the assumption that the history of life on Earth is typical?

- Would they expect life on another world to resemble life on Earth?

The Sun has only lived roughly half its lifetime as a main sequence star, and should be habitable for another billion years or more*. Ask your students how they imagine future life on Earth might be different than life on Earth today.

*The Sun, like all stars is getting brighter as it ages. In one to two billion years, the Sun will grow bright enough that Earth's oceans will begin to dry out from evaporation and the water in the atmosphere will be lost to space. Many planetary scientists think that in someday the Earth will be very much like the planet Venus is today: very hot, extremely dry, and inhospitable to life.

Pleiades Star Cluster

Eventually these "seven sisters" will drift apart.

Image ***Credit:*** *NASA, ESA and AURA/Caltech*

An open cluster of stars, like the Pleiades, is a group of stars that started together in a stellar nursery.

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Lifetimes of Stars

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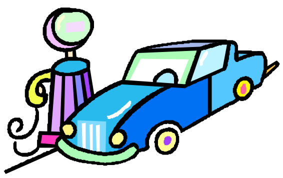

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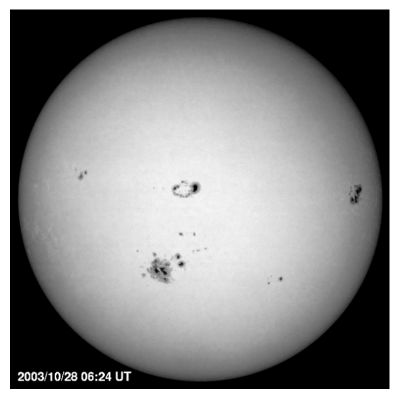

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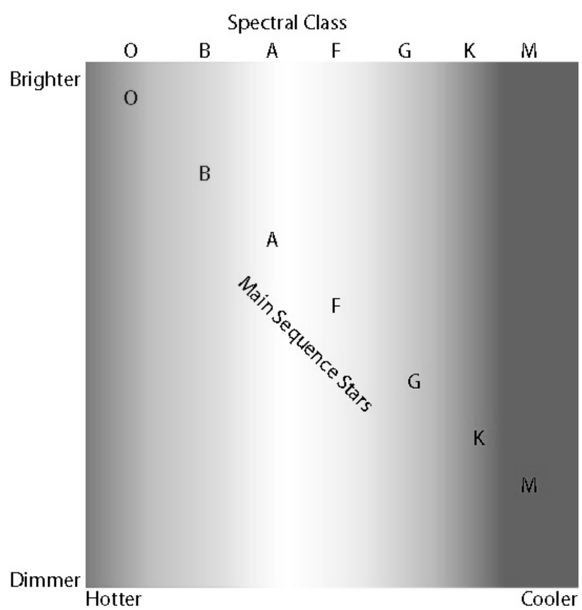

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- Start about 12 cm above the bottom of the pages for the first star class.
- Add a separate line above the first one for each class of star. Make them about one cm apart. **Colored lines matching the color of each class of stars are recommended.**
- Some star classes will be longer than the span of 4.5 billion years (the total of your pages). In these cases, on the last page use an arrow at the end of the line for that star to indicate a longer life span than is shown on the timeline.

You are now ready to add events to your timeline.

Example: The oldest surviving rocks on the Earth are about 4 billion years old, so they formed about 0.5 billion or 500 million years after the formation of the Earth.

How far from the beginning of the timeline do we mark this event?

(Time of Event from Beginning of Timeline)/ Scale Factor
= Distance from Beginning of Timelineso

500 million years / 20 million years per cm = 25 cm
(which also happens to be one sheet of paper).

- How would this change if you wanted to calculate the distance on your timeline measured from the end of the timeline (the present)?

Put major events from the history of the Earth on the timeline

Take the events given in the **Table 2** (**Some Major Events in the History of the Earth**) and mark each of them on them on the timeline. You may use the space both above and below your timeline.

- The times of the events in the table are given in both years from Earth's formation and years from the present (how many years ago an event occurred). Both numbers have been provided so that you can easily work from either end of your timeline.

Comparing Stellar Lifetimes to the History of Life on Earth.

Which classes of stars have shorter lifetimes than the Earth has had so far?

Assume that a star of each class was born at the same time as our own sun. For each class of stars with lifetimes shorter than the age of the Earth, answer these questions:

- What was the Earth like over the time period that the star would have been on the main sequence?

- Did life exist on the Earth before the star died? If so, what type?

Table 1: Lifetimes of Stars

Class	Color	Mass *	Lifetime on Main Sequence	How Many Times the Lifetime of the Sun?
O	Blue White	40 x M_{Sun}	3 million years	
B	Blue White	6.5 x M_{Sun}	80 million years	
A	White	2.1 x M_{Sun}	1.5 billion years	
F	Pale Yellow to White	1.3 x M_{Sun}	5 billion years	
G	Yellow	M_{Sun}	10 billion years	1
K	Orange	0.7 x M_{Sun}	35 billion years	
M	Red	0.2 X M_{Sun}	250 billion years	

* $\mathbf{M_{Sun}}$ is the mass of the Sun. The mass of the Sun is 2,000,000,000,000,000,000 trillion kilograms (or 2×10^{30} kg)!

This table is for **main sequence** stars, a representative star for each class.

Table 2: Some Major Events in the History of the Earth

Event	Comments	Years since Earth's formation	Years ago
Earth formed	Frequent impacts with asteroids and comets will continue for at least 500 million more years	---	4.5 billion
Oldest known rocks formed (Crystals called zircons may be older.)	Older rocks were destroyed by asteroid and comet impacts or by plate tectonics	500 million	4.0 billion
Oldest evidence for life	chemical "fossils"	800 million	3.8 billion
Oldest fossils of single cells	fossils look like modern bacteria	1,100 million (or 1.1 billion)	3.4 billion
Oldest known cells like our own	called eukaryotes, these cells are more complex than bacteria	2,400 million (or 2.4 billion)	2.1 billion
First known fossil animals and plants	Before this time, only single-celled creatures were abundant	3,900 million (or 3.9 billion)	600 million
First fish	The first animals with backbones?	(4,000 million) (or 4.0 billion)	500 million
First land plants	Plants with flowers and seeds develop in 270 million more years	4,100 million (or 4.1 billion)	400 million
First amphibians	Amphibians and insects begin to conquer the land	4,150 million (or 4.15 billion)	350 million
First reptiles	Unlike amphibians, reptiles could move away from water to colonize the land	4,200 million (or 4.2 billion)	300 million
Dinosaurs appear	*Eoraptor* was only a meter long	4,273 million (or 4.273 billion)	228 million
First mammals	These first mammals were small mouse-like creatures that laid eggs!	4,280 million (or 4.28 billion)	220 million
First birds	The first bird was called *Archaeopteryx*	4,350 million (or 4.35 billion)	150 million
Extinction of dinosaurs	Many scientists believe this was caused by an asteroid impact	4,435 million (or 4.435 billion)	65 million
Early humans	*Homo habilis* made and used stone tools	4,496 million (or 4.496 billion)	2 million
Modern humans	These people looked like people today	4.49987 billion	130,000
Civilization	People began growing crops, making permanent homes, etc.	4.49999 billion	10,000

Note: All times are approximate, and may change with as new fossil evidence is discovered.

Betelgeuse

(Image Credit: HST/NASA, Observer: A. Dupree) (CfA)).

Betelgeuse is a red supergiant in the constellation of Orion. It is also the first star, other than the Sun, that's size can be directly measured from a telescope image.

In this Exploration, find out:

- *Why are dying stars much bigger than their main-sequence counterparts?*
- *What are the relative sizes of dying stars, and stellar remnants, compared to objects in our solar system?*
- *Will the Sun ever go supernova?*

Death of Stars Teacher Guide

In this exercise, students will model the sizes of dying stars (which have left the main sequence), and stellar remnants for the purpose of exploring the wide range of sizes of stellar objects. The lesson uses the same 1:10 billion scale factor as used in the Scale Model Solar System, Sizes of Stars, and Stellar Distances lessons for easy comparison to our own solar system and main sequence stars. (Main sequence refers to stars during the main part of their "lives" during which they convert hydrogen to helium in their cores).

Recommend Prerequisites: Scale Model Solar System, Sizes of Stars

Grade Level: 6-8

Curriculum Standards: The Death 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)

Time Frame: The activity should take approximately 45 minutes to 1 hour to complete, including a short introduction and follow-up.

Purpose: To aid students in understanding how stars are born, the relative numbers of stars of different masses born in interstellar clouds, and the lifetimes of stars.

Key Concepts:

- Dying stars can be much bigger than main sequence stars.
- The objects left behind when a star dies — a white dwarf, neutron star, or black hole — are the size of the Earth or smaller.
- Our own star, the Sun, will never go supernova.

Required Supplies:

- A copy of the student instruction sheet for each student
- Size table from the Scale Model Solar System activity
- Distance table from the Scale Model Solar System activity

Recommended Supplies:

- A large grapefruit or 14 cm diameter ball (for the present-day Sun)
- A cherry tomato or small red ball that is about 3 cm or about 1” in diameter (to represent a main sequence M class star)
- A blue candy sprinkle or planet card for the Earth from the Scale Model Solar System activity
- A white candy sprinkle (taped onto a black card to help make it visible.)
- A map of your city or region
- A metric ruler for every student or small group of students

Introduction:

Ask the students what they think happens to stars after they run out of hydrogen in their cores and leave the main sequence.

- What will be the final fate of a star like the Sun?
- Are main sequence stars the largest stars, smallest stars, or are they neither?
- 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.

Review Scale Factors:

Review the usefulness of the scale factor in the Scale Model Solar System and/or Sizes of Stars activities. 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 and to stars on the main sequence.

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

Most of the stars in the solar neighborhood shine by converting hydrogen to helium, and are therefore on the main sequence. Many of the brightest stars we see from the Earth are dying stars that have left the main sequence, meaning they no longer have hydrogen in the cores to convert to helium.

Discussing fusion with your students: As mentioned in the Sizes of Stars activity**,** the Benchmarks for Science Literacy recommend that students in grades 6-8 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.

In the Sizes of Stars activity, students may have asked where the heat inside a star comes from initially so that fusion can begin. Students may now wonder how a star can begin using heavier elements for fuel when they didn't before.

Once again, the answer is gravity. Without hydrogen fusion as a source of energy, the star begins to collapse. As it collapse it heats up. When the core is sufficiently dense and hot, fusion of elements heavier than hydrogen begins.

Effect on Class

As on the main sequence, star colors are a function of temperature, with blue for a hot star and red for a cool star. However, unlike stars on the main sequence, star colors for dying stars are not strictly a function of the mass of the star. Not all giants will be red. As they evolve, stars can shrink and expand, changing their colors. At their largest, however, they will be red.

The Main Sequence and the Light We See

While on the main sequence, stars shine because they are converting the element hydrogen into the element helium in their cores. Energy is given off in the process, and that energy is what allows a star to shine:

4 hydrogen atoms

+
heat and pressure

=
1 helium atom
+ energy

Leaving the Main Sequence:

Dying Stars

When a star runs out of hydrogen in its core, it starts to collapse because of its own gravity. As it collapses, the core gets hotter and the pressure increases.

Stars about the mass of the Sun and bigger have higher pressures and temperatures so new fusion reactions can occur that release energy.

Once these reactions start, they keep the core of the star from collapsing further. The first new reaction converts helium to carbon:

3 helium atoms

+

heat and pressure

=

1 carbon atom

+ energy

*When a star begins to use helium for its fuel, the core is smaller than it was on the main sequence. But the outer layers of the star expand. This happens because the fusion reaction converting helium into carbon produces much more energy than the reaction that converts hydrogen to helium. The energy makes the star shine much more brightly than it did before. In fact, the star produces so much energy that gravity can't hold tightly on to the outer layers of the star. This extra energy puffs up the star. Relatively low mass stars will become giant stars, and high mass stars will become **supergiant** stars, like the star Betelgeuse shown above.*

How Dying Stars Change Classes

When the outer layers of a star puff up, they cool. A star that no longer shines by converting hydrogen to helium may be very bright compared with a star of the same mass that is still on the main sequence. But, its surface temperature may also be much cooler, and therefore its color will be redder. The class of a star depends on the temperature of the surface of the star.

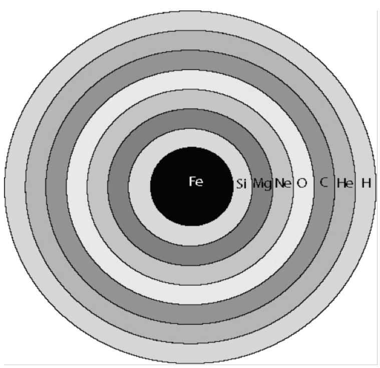
Beyond Helium

*The helium in the core of a star is converted to carbon much more rapidly than the hydrogen was converted to helium. What happens when the helium starts to run out? The core of the star will begin to collapse again. If the star has enough mass, it will begin converting carbon into oxygen. For very high mass stars with masses of about 8 times the mass of the Sun or larger (B and O class stars on the main sequence), this cycle will repeat until the element silicon has been converted to iron. Reactions involving iron do not produce extra energy, no matter how small the core becomes. When a star has used up its fuel, and has built up iron its core, it has reached the **iron limit**.*

Each time the core collapses an outer layer of the core does not participate in the new reaction. The new elements *created in the star build up around the core in an "onion skin" structure, with lighter elements on the outside, and heavier elements on the inside. All of the elements that make up planets and everything on them (with the exception of hydrogen and some helium) are created in stars. Without the fusion reactions that produce energy in massive stars, the Earth and life would not exist.*

Onion Skin Model

For a high-mass star, the core will build up successively more massive elements, with iron (and nickel) building up in the center.



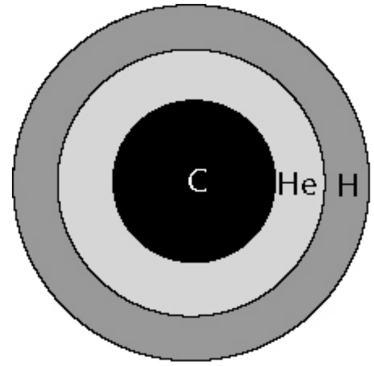
Onion Skin Model to Iron: In massive stars, the onion skin structure of the core builds in successive layers all the way to iron. The illustration shown for students is of a simplified version of the onion skin model representing a Sun-like star.

Elements Heavier Than Iron: Your students may ask where elements heavier than iron originate. They too, are produced in stars by a process called neutron capture. Understanding this process requires a discussion of subatomic particles, which is why it has not been described in the student reading. If your students ask, however, you may wish to discuss it.

In brief, the other nuclear reactions in the star produce high-energy neutrons. Sometimes an atom captures a neutron, changing the nature of the atom. A neutron can decay into a proton and electron, and so new elements can be produced. (An antineutrino is also produced in the process, but this is too much information for middle school.)

Elements produced in this way, like copper, silver, and gold, are much more rare than lighter elements like carbon, oxygen, silicon, or iron. Nickel, although heavier than iron

Onion Skin Model



The onion skin model illustrates the layered structure of the cores of dying stars. As lighter elements are made into heavier elements inside stellar cores through the process of nuclear fusion, layers of different material build up, with the heaviest elements closest to the center of a star.

In a massive star, like Cassiopeia A was before it exploded, layers of successively higher mass elements build up, with iron forming as the final product of normal fusion reactions in the core.

Cassiopeia A as seen by Spitzer Space Telescope in 2006. The infrared telescope actually saw the onion skin layers that were blown off when the star went supernova.

(See image and story at http://www.spitzer.caltech.edu/Media/releases/ssc2006-19/release.shtml.)

is an “iron family” element, and is produced by silicon fusion at the same time iron is being produced.

Background: A More Compete Story of Stellar Evolution

The actual evolution of stars off of the main sequence is more complex than given in this lesson for middle school students. The following information is provided to give the teacher a more complete picture of stellar evolution should questions arise:

As the core of a star begins to run out of each elemental fuel, the core collapses again. This collapse compresses the core, increasing its temperature and pressure. The area immediately surrounding the core is also compressed. As a star leaves the main sequence, but before helium fusion begins, a shell around the core will begin hydrogen fusion. It is during this time that the star begins to swell into a red giant or red supergiant, depending upon its mass. Once the core is sufficiently hot and dense (with a temperature of about 200 million K), helium fusion will begin. Helium fusion produces much more energy than hydrogen fusion, and the star heats up again, increasing in spectral class. A sun-like star will become an orange (K-class) or yellow (G-class) giant, before becoming a red giant again. A massive star may become a white or blue (A or B class) supergiant, before again returning to a red supergiant phase. Stars a few times more massive than the Sun will pass through a stage as a yellow giant star called a Cephid variable.

Each successive new “fuel” will require greater core temperatures and pressures. The gravity of stars provides the force that compresses their cores. Once carbon fusion begins, a massive star builds up the onion-skin of elements in its core very quickly, in mere hundreds of years. The internal changes happen so fast during the later stages of fusion that no change in spectral classes will be visible to astronomers observing the star.

Regardless of its surface temperature, a giant/supergiant star will be much larger and continue to shine with a tremendous amount of energy compared with its time on the main sequence. This stellar dying process is about 10% as long as a star’s main sequence lifetime.

For more information on stellar evolution check out the following Web resources:

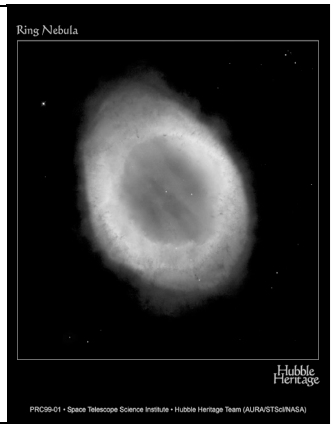
NASA’s Imagine the Universe Teacher Corner:
http://imagine.gsfc.nasa.gov/docs/teachers/lifecycles/stars.html

Australia Telescope Education and Public Outreach:
http://outreach.atnf.csiro.au/education/senior/astrophysics/stellarevolution_postmain.html

The End of a Sun-like Star:

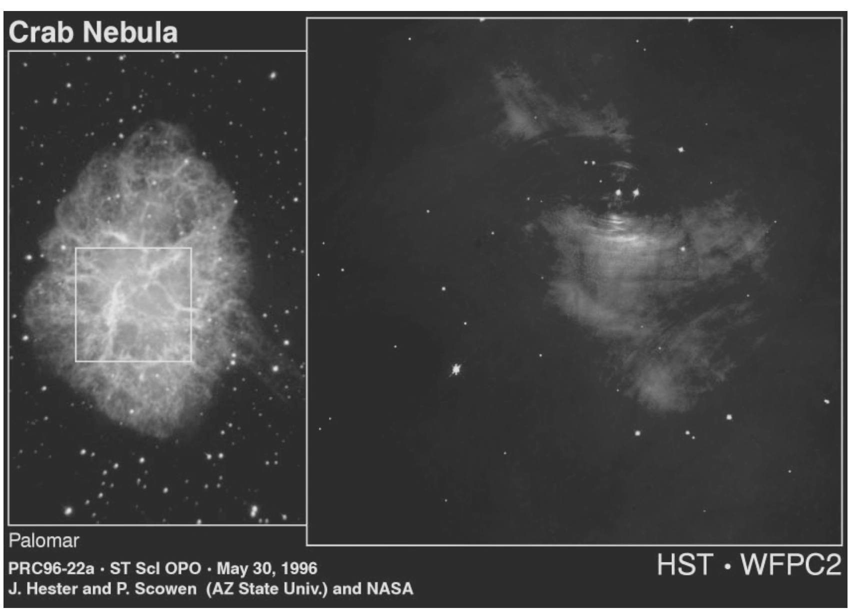
When a star like the Sun can no longer sustain fusion, its core collapses for a final time. The outer layers of the star are lost, and surround the core in a cocoon of glowing gas. The core of the star is now a white dwarf - a hot, but very dim object that is no longer producing new energy. Like a hot coal taken out of a fire, it will slowly cool, becoming more dim and red. The outer layers of the star will also cool and fade, but before they do they will shine as a planetary nebula. (A planetary nebula has nothing to do with planets, but gets its name from the round shape.)

This image of the Ring Nebula, taken by the Hubble Space Telescope, shows the expanding outer layers of the once red giant star surrounding the white dwarf that was once the star's core.



The End of a High-Mass Star:

Stars with masses of about 8 times the mass of the Sun experience a much more dramatic demise than lower mass stars like the Sun. When these stars run out of fuel by reaching the iron limit, the core collapses very fast (perhaps in only a few seconds!), and the outer layers of the star are blown off in a massive explosion known as a ***supernova****.* ***Supernovae*** *explosions release an almost unbelievable amount of energy.*



In 1054 A.D., Chinese astronomers recorded a supernova explosion that was seen as a star so bright that it was visible during the day for more than three weeks. Today, the ***Crab Nebula****, a supernova remnant, can be seen in the location of that mysterious new "star" seen nearly 1000 years ago.*

The fate of the remaining part of the core of the high mass star is also much more exciting than what happens to the core of a lower mass star. And exactly what that fate will be depends on the final mass of the core. If the core has a mass greater than 1.4 times the mass of the Sun, then the core's own gravity will be strong enough to squeeze all of the empty space out of the core's atoms. If the mass is less than about 3 times the mass of the Sun, what is left is a very small, extremely dense object known as a ***neutron star****. When the collapsing core is more massive than this limit, it continues collapsing and becomes one of the strangest objects in our universe: a* ***black hole****.*

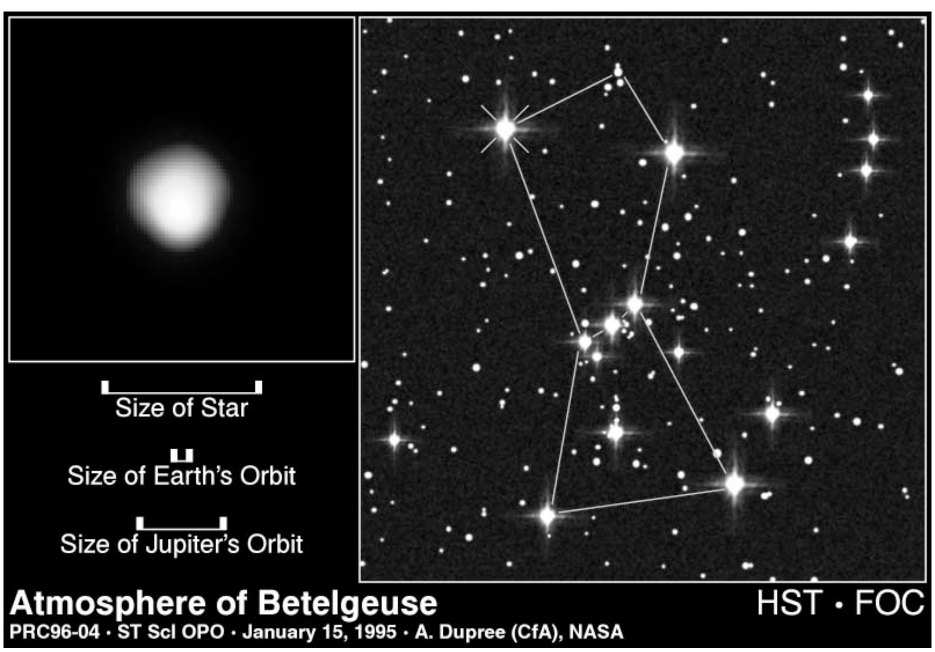
Death of Stars Exercises:

Have students complete the exercises either individually or in small groups.

Make sure the students have a copy of the Size Table and the Distance Table from the Scale Model Solar System activity handy.

The Sun will fill the present orbit of the Earth, and perhaps even Mars, during its final red giant phase. However, by that time the future Sun it will have also lost mass. Less mass means less gravity, and the Earth's orbit may expand to beyond the reach of the bloated star.

Giants, and especially supergiants like Betelgeuse, are the largest, and brightest stars. Betelgeuse is about 1400 light years away, but is one of the brightest stars in our sky.



Exercise 1:

Using the diameter of the Sun and the scale factor of 1:10 billion, complete Table 1.

Table 1: Red Giants and Supergiants

	Mass	Diameter/ Diameter of the Sun	Actual Size (in billions of meters)	Scaled Size (in meters)
Red Giant (future Sun)	1 x M_{Sun}	~200	**~278 billion meters**	**~27.8 m**
Red Supergiant (Betelgeuse)	~18 x M_{Sun}	~1000	**~1390 billion meters**	**~139 m**

The diameter of the Sun is 1.392 billion meters.

By Hubble measurements, Betelgeuse is even bigger than the estimate given here!

Exercise 2:

Compare the scaled sizes for a red giant and a red supergiant to the distances of the planets in the solar system. (Hint: divide the diameter by two to get the radius to make your comparison easier.)

- *When the Sun becomes a red giant, it will reach closest to the orbit of which planet?* **Earth**
- *If the supergiant star Betelgeuse replaced the Sun, it would extend out to the orbit of which planet?* **Jupiter**

Exercise 3:

Using the scale factor of 1:10 billion, complete Table 2.

Table 2: Sizes of White Dwarfs, Neutron Stars, and Black Holes

	Mass	Diameter	Scaled Size (in mm)
White Dwarf	0.7 x M_{Sun}	~10,000 km	**~1 mm**
Neutron Star	1.4 x M_{Sun}	~30 km	**~.003 mm**
Black Hole	~3 x M_{Sun} or more	~18 km or more	**~0.0018 mm**

** The "diameter" of a black hole is not actually a real size, but represents the region around the black hole that has such intense gravity that even light can't escape.*

Exercise 4:

*Compare the size of a typical white dwarf, as shown in **Table 1** to the sizes of the planets using the **Size Table** from the **Scale Model Solar System** activity.*

- *Which planets are closest to the size of a white dwarf?* **Earth and Venus**

- *What object could you use to represent a white dwarf in a scale model that uses the scale factor of 1:10 billion?* **candy sprinkle (white)**

Exercise 5:

*Compare the size of the neutron star and black hole in **Table 2** to the sizes of the planets.*

- *Would you be able to see an object the size of either a neutron star or a few solar mass black hole on the scale model?* **No.**

  Why or why not? **Both are too small for a 1:10 billion scale model.**

Things to Think About:

- *If a blue-white B class leaves the main sequence, and its outer layers swell and turn red, what is the new class of that star?* ***M-class.***

Why? Color, or more accurately, surface temperature, determines spectral class.

- When the Sun becomes a red giant, its mass will not go up. (In fact, the Sun will lose mass). How will the density of the future red giant Sun compare with the density of the main sequence Sun shining today?

Because the future red giant Sun will have the same amount of mass (or less) as the current Sun, but in a much greater volume, its density will be much less.

- Imagine if a planet orbiting a very massive star somehow managed to survive the star going supernova without its orbit being affected by the powerful explosion. Would this planet be pulled in to the black hole left behind by the supernova because of the black hole's gravity? **No.**

Black holes and gravity are difficult concepts, for adults as well as children.

Black holes left behind when a star goes supernova always have **less mass** than the original star. That means they have **less gravity** at a given distance from the center of the black hole. Very close to the black hole the gravity is intense because all the matter is concentrated in tiny space. For example, a spacecraft could never get within 5 km of the center of a normal star, and even if it did, the mass of the star would surround the spacecraft.

Distance, as well as mass, matters for gravity. Because the spacecraft is *outside* the star, and therefore millions or billions of km away from the star's center of mass, the gravity the gravitational force on it would be **much less** than for a spacecraft near the event horizon of a black hole with the same mass as the star.

At a distance of billions of km from the center of mass of a 3 solar mass star, a spacecraft would not encounter the intense gravity that the same spacecraft would within a mere 5 km of a black hole 3 times the mass of the Sun.

Follow-up:

After the students have had a chance to read through the student sheet (individually or as a class), discuss the concepts presented in the information sheet.

When the exercises have been completed, discuss those results as well. Using objects such as the grapefruit for the present-day Sun, and the blue candy sprinkle or planet card for the Earth from the Scale Model Solar System activity as visual aids for the students may help them better understand how giants, supergiants, and white dwarfs relate to the sizes of objects in our solar system.

If possible, consider taking the students to an area such as the schoolyard or a long hallway with about 80 meters of space available, and walk the distance to that corresponds to the radius of a red giant and a red supergiant. To help your students compare evolved stars to their main class counterparts, consider bringing along

- the grapefruit that represents the present-day Sun on this scale and
- the cherry tomato or small red ball to represent a main sequence M class star

A map of your city or region can be used to help your students understand the actual sizes of a neutron star and the event horizon of a black hole. The size of a neutron star is often compared to the size of Manhattan Island.

Extension:

If you have Internet access for students working in small groups, or you can make high quality color printouts from the Web, consider having students look at some of the many planetary nebulae, a supernova remnant, and a lone neutron star imaged by the Hubble Space Telescope. For images of stellar remnants taken in non-visible wavelengths of light, try the galleries of these other two of NASA's four Great Observatories:

- Spitzer Space Telescope (infrared) at http://www.spitzer.caltech.edu/
- Chandra X-Ray Observatory at http://chandra.harvard.edu/.

Hubble Images:

- The Ring Nebula (M57), the most famous planetary nebula
  http://hubblesite.org/newscenter/newsdesk/archive/releases/1999/01/
- The Glowing Eye of NGC 6751
  http://hubblesite.org/newscenter/newsdesk/archive/releases/2000/12/
- Cat's Eye Nebula
  http://hubblesite.org/newscenter/newsdesk/archive/releases/2004/27/
- Stingray Nebula: a very young planetary nebula.
  http://oposite.stsci.edu/pubinfo/pr/1998/15/
- The “Eskimo” Nebula: A Planetary Nebula
  http://hubblesite.org/newscenter/newsdesk/archive/releases/2000/07/image/a
- The Hourglass Nebula, another planetary nebula (not spherical at all)
  http://hubblesite.org/newscenter/newsdesk/archive/releases/1996/07/
- The "Rotten Egg" Nebula: A Planetary Nebula in the Making
  http://hubblesite.org/newscenter/newsdesk/archive/releases/1996/05/
- Dying Sun-like Star
  http://hubblesite.org/newscenter/newsdesk/archive/releases/1996/05/
- The Crab Nebula (A Supernova Remnant)
  http://www.seds.org/messier/more/m001_hst.html
- Nearby Supernova Remnant
  http://imgsrc.hubblesite.org/hu/db/2005/15/images/a/formats/web_print.jpg
- Hubble Sees a Neutron Star Alone in Space
  http://hubblesite.org/newscenter/newsdesk/archive/releases/1997/32/

Comparison images with Hubble, Spitzer and Chandra:

- Kepler’s Supernova
  http://hubblesite.org/newscenter/archive/releases/2004/29/
- Super Massive Black Holes
  http://hubblesite.org/newscenter/archive/releases/2004/19/
- Cassiopeia A Supernova Remnant
  http://www.spitzer.caltech.edu/Media/releases/ssc2005-14/ssc2005-14c.shtml

Betelgeuse

(Image Credit: HST/NASA, Observer: A. Dupree) (CfA)).

Betelgeuse is a red supergiant in the constellation of Orion. It is also the first star, other than the Sun, that's size can be directly measured from a telescope image.

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Death of Stars

Most of the stars in the solar neighborhood shine by converting hydrogen to helium in their cores, and are therefore on the *main sequence*. Many of the brightest stars we see from the Earth are dying stars that have left the *main sequence*, meaning they no longer have hydrogen in the cores to convert to helium.

When a star begins to use helium for its fuel, the core is smaller than it was on the main sequence. But the outer layers of the star expand. This happens because the fusion reaction converting helium into carbon produces much more energy than the reaction that converts hydrogen to helium. The energy makes the star shine much more brightly than it did before. In fact, the star produces so much energy that gravity can't hold tightly on to the outer layers of the star. This extra energy puffs up the star. Relatively low mass stars will become giant stars, and high mass stars will become **supergiant** stars, like the star Betelgeuse shown above.

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While on the main sequence, stars shine because they are converting the element hydrogen into the element helium in their cores. Energy is given off in the process, and that energy is what allows a star to shine:

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+

heat and pressure

=

1 helium atom
+ energy

Leaving the Main Sequence:

Dying Stars

When a star runs out of hydrogen in its core, it starts to collapse because of its own gravity. As it collapses, the core gets hotter and the pressure increases.

Stars about the mass of the Sun and bigger have higher pressures and temperatures so new fusion reactions can occur that release energy.

Once these reactions start, they keep the core of the star from collapsing further. The first new reaction converts helium to carbon:

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+

heat and pressure

=

1 carbon atom

+ energy

How Dying Stars Change Classes

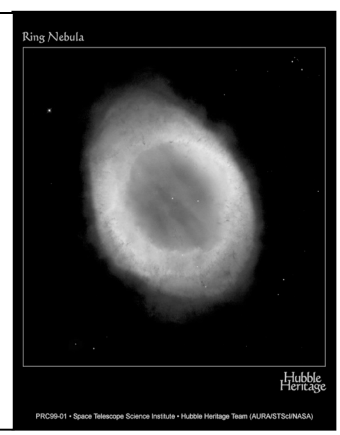
When the outer layers of a star puff up, they cool. A star that no longer shines by converting hydrogen to helium may be very bright compared with a star of the same mass that is still on the main sequence. But, its surface temperature may also be much cooler, and therefore its color will be redder. The *class* of a star depends on the *temperature of the surface* of the star.

Beyond Helium

The helium in the core of a star is converted to carbon much more rapidly than the hydrogen was converted to helium. What happens when the helium starts to run out? The core of the star will begin to collapse again. If the star has enough mass, it will begin converting carbon into oxygen. For very high mass stars with masses of about 8 times the mass of the Sun or larger (B and O class stars on the main sequence), this cycle will repeat until the element silicon has been converted to iron. Reactions involving iron do not produce extra energy, no matter how small the core becomes. When a star has used up its fuel, and has built up iron its core, it has reached the **iron limit**.

Each time the core collapses an outer layer of the core does not participate in the new reaction. The new elements created in the star build up around the core in an "onion-skin" structure, with lighter elements on the outside, and heavier elements on the inside. All of the elements that make up planets and everything on them (with the exception of hydrogen and some helium) are created in stars. Without the fusion reactions that produce energy in massive stars, the Earth and life would not exist.

This image of the Ring Nebula, taken by the Hubble Space Telescope, shows the expanding outer layers of the once red giant star surrounding the white dwarf that was once the star's core.



The End of a Sun-like Star:

When a star like the Sun can no longer sustain fusion, its core collapses for a final time. The outer layers of the star are lost, and surround the core in a cocoon of glowing gas. The core of the star is now a white dwarf - a hot, but very dim object that is no longer producing new energy. Like a hot coal taken out of a fire, it will slowly cool, becoming more dim and red. The outer layers of the star will also cool and fade, but before they do they will shine as a planetary nebula. (A planetary nebula has nothing to do with planets, but gets its name from the round shape.)

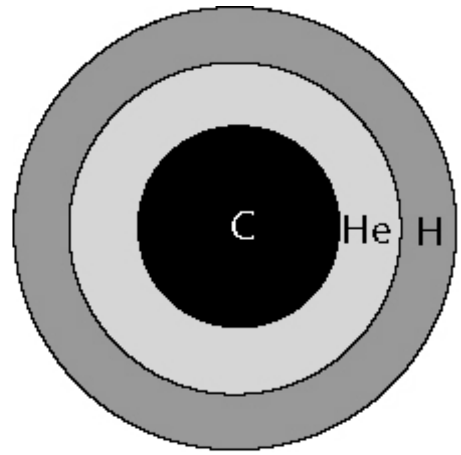
The End of a High-Mass Star:

Stars with masses of about 8 times the mass of the Sun experience a much more dramatic demise than lower mass stars like the Sun. When these stars run out of fuel by reaching the iron limit, the core collapses very fast (*perhaps in only a few seconds!*), and the outer layers of the star (and part of the core) are blown off in a massive explosion known as a **supernova**. **Supernovae** explosions release an almost unbelievable amount of energy.

In 1054 A.D., Chinese astronomers recorded a supernova explosion that was seen as a star so bright that it was visible during the day for more than three weeks. Today, the **Crab Nebula**, a supernova remnant, can be seen in the location of that mysterious new "star" seen nearly 1000 years ago.

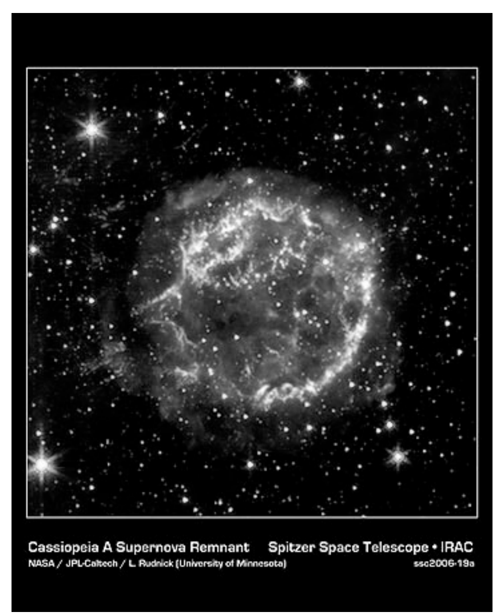
The fate of the remaining part of the core of the high mass star is also much more exciting than what happens to the core of a lower mass star. And exactly what that fate will be depends on the final mass of the core. If the core has a mass greater

Onion Skin Model



The onion skin model illustrates the layered structure of the cores of dying stars. As lighter elements are made into heavier elements inside stellar cores through the process of nuclear fusion, layers of different material build up, with the heaviest elements closest to the center of a star.

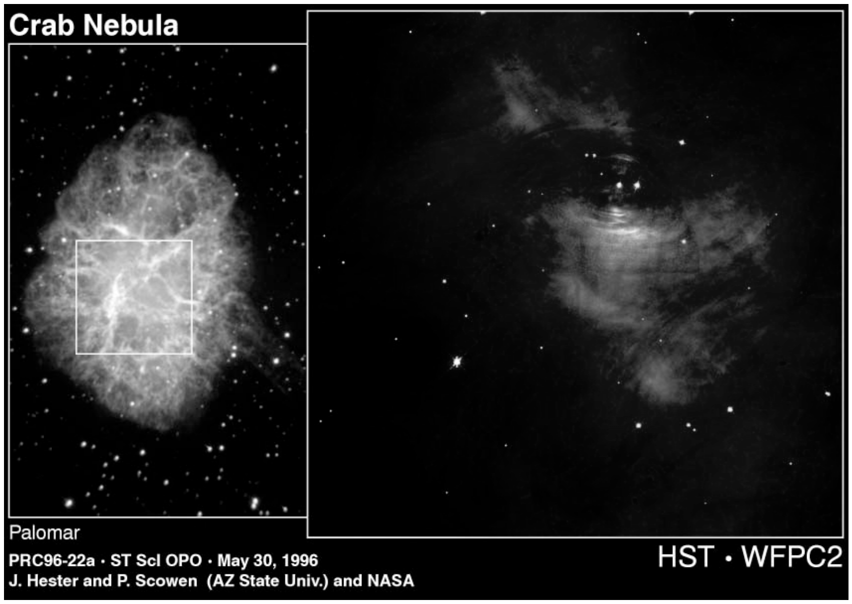
In a massive star, like Cassiopeia A was before it exploded, layers of successively higher mass elements build up, with iron forming as the final product of normal fusion reactions in the core.



Cassiopeia A as seen by Spitzer Space Telescope in 2006. The infrared telescope actually saw the onion skin layers that were blown off when the star went supernova.

(See image and story at http://www.spitzer.caltech.edu/Media/releases/ssc2006-19/release.shtml.)

than 1.4 times the mass of the Sun, then the core's own gravity will be strong enough to squeeze all of the empty space out of the core's atoms. If the mass is less than about 3 times the mass of the Sun, what is left is a very small, extremely dense object known as a **neutron star**. When the collapsing core is more massive than this limit, it continues collapsing and becomes one of the strangest objects in our universe: a **black hole**.



Death of Stars Exercises:

Exercise 1:

Using the diameter of the Sun and the scale factor of 1:10 billion, complete Table 1.

Table 1: Red Giants and Supergiants

	Mass	Diameter/ Diameter of the Sun	Actual Size (in billions of meters)	Scaled Size (in meters)
Red Giant (future Sun)	1 x M_{Sun}	~200		
Red Supergiant (Betelgeuse)	~18 x M_{Sun}	~1000		

The diameter of the Sun is 1.392 billion meters.

Exercise 2:

Compare the scaled sizes for a red giant and a red supergiant to the distances of the planets in the solar system. (Hint: divide the diameter by two to get the radius to make your comparison easier.)

- When the Sun becomes a red giant, it will reach closest to the orbit of which planet? ____
- If the supergiant star Betelgeuse replaced the Sun, it would extend out to the orbit of which planet? ____________________________________

Exercise 3:

Using the scale factor of 1:10 billion, complete Table 2.

Table 2: Sizes of White Dwarfs, Neutron Stars, and Black Holes

	Mass	Diameter	Scaled Size (in mm)
White Dwarf	0.7 x M_{Sun}	~10,000 km	
Neutron Star	1.4 x M_{Sun}	~30 km	
Black Hole	~3 x M_{Sun} or more	~18 km or more	

* The "diameter" of a black hole is not actually a real size, but represents the region around the black hole that has such intense gravity that even light can't escape.

Exercise 4:

Compare the size of a typical white dwarf, as shown in **Table 1** to the sizes of the planets using the **Size Table** from the **Scale Model Solar System** activity.

- Which planets are closest to the size of a white dwarf?

  ____

- What object could you use to represent a white dwarf in a scale model that uses the scale factor of 1:10 billion?_______________________________________

Exercise 5:

Compare the size of the neutron star and black hole in **Table 2** to the sizes of the planets.

- Would you be able to see an object the size of either a neutron star or a few solar mass black hole on the scale model?__________________________________

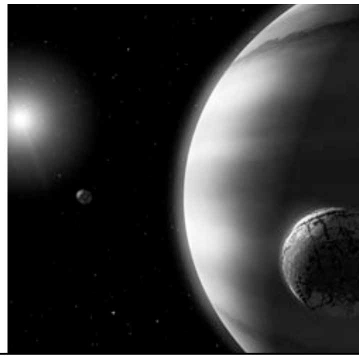
  Why or Why not?

Things to Think About:

- If a blue-white B class star leaves the main sequence, and its outer layers swell and turn red. What is the new class of that star?

- When the Sun becomes a red giant, its mass will not go up. (In fact, the Sun will lose mass). How will the density of the future red giant Sun compare with the density of the main sequence Sun shining today?

- Imagine if a planet orbiting a very massive star somehow managed to survive the star going supernova without its orbit being affected by the powerful explosion. Would this planet be pulled in to the black hole left behind by the supernova because of the black hole's gravity?



Artist Conception Courtesy
NASA/JPL-Caltech

Artist's conception of an extrasolar gas giant. planet

In this Exploration, find out:

- How and when were the outermost planets in our own solar system discovered?
- What are the problems in hunting for other (extrasolar) planets?
- How can astronomers find a planet without really "seeing it"?

Planet Hunting 1: Finding Planets Teacher Guide

In Part One of this two-part exercise, students will learn about the historical discoveries of the outer three planets in our solar system, some of the challenges involved in ongoing efforts to find planets around other stars, and the ways astronomers currently search for planets. In Part Two, the students will learn about the planetary systems astronomers have found around other stars, make scale models of some of these systems, and compare them to our solar system. Students will also learn about exciting new technologies that may help astronomers find Earth-like planets in the future. This activity builds upon the other activities in the *Stars and Planets* program, especially the Scale Model Solar System, Sizes of Stars, and Stellar Distances activities, and is intended to be the final activity in the sequence. Like the other lessons in the program, Planet Hunting is a math activity as well as a science activity.

Recommend Prerequisites: Scale Model Solar System, Sizes of Stars, Stellar Distances, and Lifetimes of Stars

Grade Level: 6-8

Curriculum Standards: The Planet Hunting Part One 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)

Time Frame: The activity should take approximately 45 minutes to 1 hour to complete, including a short introduction, discussion, demonstrations, and follow-up. The student readings will take additional time and may be assigned as homework.

Purpose: To bring together the concepts presented in the previous *Stars and Planets* lessons in an investigation of the challenges astronomers face in the ongoing search for extrasolar planets. Students will also be introduced to the Astronomical Unit (AU).

Key concepts:

- Some planets in our own solar system cannot be seen with out a good telescope, and were only discovered in the past few centuries.
- Planets shine by reflecting light from their parent star.
- Stars are much brighter than planets.
- Planets can be detected without being "seen".

Supplies for Planet Hunting Part 1:

- A copy of the student handout for part 1 for each student
- A blue candy sprinkle taped to a black card or piece of construction paper
- A white candy sprinkle taped to a black card or piece of construction paper
- A candy sprinkle taped to the end of a toothpick
- A lamp without a shade
- A clear (unfrosted) light bulb – 100 W recommended
- One grapefruit or 14 cm yellow ball (for the Sun)*
- A map of the United States, map of the world, or globe
- A calculator for each student or small group of students*
- A single-pitch noise maker on a string (optional)
- Hula hoop to demonstrate planetary orbits (optional)

*Optional, but highly recommended. Objects should be the same or similar to those used in the Scale Model Solar System and Sizes of Stars activities.

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

Introduction:

Begin the activity by asking the students some questions about their own observations of planets in our solar system.

- Have any of the students seen planets in the sky, and if so, which ones?
- Have any of the students seen a planet in a telescope? If so, which one(s)?
- Do any of the planets appear to be as bright as stars?

If the students will complete the student reading as homework before doing the lesson in class, try to introduce the lesson in a brief discussion before the end of the class in which you make the assignment. Whether or not you assign the student sheet as homework, discuss the information and questions in the student sheet with the class the day of the activity.

The Discovery of Planets in Our Own Solar System:

Civilizations across the globe have known of Mercury, Venus, Mars, Jupiter, and Saturn since ancient times. The two outermost planets, and the dwarf planets, were all discovered in the past few centuries, and with the aid of telescopes. Before Uranus was discovered, astronomers didn't expect to find any planets other than the five visible with the unaided eye and the Earth. Why are Uranus and Neptune harder to see from the Earth than the other five planets? Why wasn't dwarf planet Pluto discovered until the 20th century?

*Comparing the sizes and distances of the planets will help you answer these questions. The diameters and average distances from the Sun for the planets in our solar system are given in Table 1. An easy way to compare average distances between the planets is to look at them in terms of the Earth-Sun distance, which is called an **Astronomical Unit**. The symbol for an Astronomical Unit is **AU**.*

Discovery of Uranus

Uranus was discovered in 1781 by musician and amateur astronomer William Herschel. Uranus was the first planet not known about by ancient people all over the world.

While observing the constellation of Gemini with a homemade telescope, Herschel discovered a unique object that didn't act like a star or a comet. After carefully recording his observations over several years, Hershel was able to show that he had found a new planet!

Uranus was named after the Greek god of the sky.

For Tables 1 and 2 complete the last columns with distances in AU using the given distance from the Sun in kilometers for each planet or dwarf planet.

Table 1: Planets in Our Solar System

Planet	***Date Discovered***	***Diameter***	***Distance from Sun***	***Distance from Sun in AU***
Mercury	*Ancient Times*	*4,878 km*	*58 million km*	0.39
Venus	*Ancient Times*	*12,104 km*	*108 million km*	0.72
Earth	-----	*12,756 km*	*150 million km*	*1.0*
Mars	*Ancient Times*	*6,794 km*	*228 million km*	1.5
Jupiter	*Ancient Times*	*142,796 km*	*778 million km*	5.2
Saturn	*Ancient Times*	*120,660 km*	*1,427 million km*	9.5
Uranus	*1781*	*51,118 km*	*2,871 million km*	19
Neptune	*1846*	*54,523 km*	*4,497 million km*	30

Table 2: Dwarf Planets in Our Solar System

Planet	Date Discovered	Diameter	Distance from Sun	Distance from Sun in AU
Ceres	1801	950 km	441 million km	2.9
Pluto	1930	2,300 km	5,913 million km	39
Eris	2003	2,400 km	10,150 million km	68

As is apparent from Table 1 and the Scale Model Solar System activity, Uranus and Neptune are far away from both the Sun and the Earth in comparison with the other planets. Even though the inner planets are all smaller than Uranus and Neptune, the fact that Mercury, Venus, and Mars are relatively close to both the Sun and the Earth makes them easy to see from our own planet. Table 2 shows that each of the dwarf planets is smaller than the eight planets, and Pluto and Eris are far from the Sun, making them doubly hard to find.

What about planets orbiting other stars?

*Planets orbiting other stars (**extrasolar planets**) are much harder to find than planets in our own solar system. The first such planet orbiting another normal main sequence star or giant star wasn't discovered until 1995!*

Review the Scale Factor:

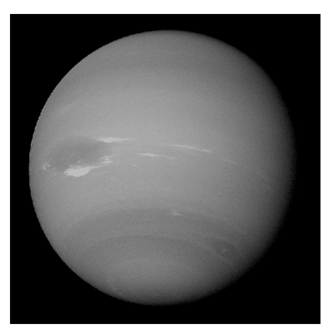
The scale factor for this scale model is 1:10 billion, and is the same as the size/distance scale used in most of the other Stars and Planets activities. If your students have done one or more of these activities, simply remind them that the scale factor is the same. Every centimeter in the model equals 10 billion real centimeters. Similarly, a kilometer in this scale model equals 10 billion kilometers.

The Discovery of Neptune and the Power of Math!

Astronomer's began the hunt for Neptune because Uranus' orbit, its path around the Sun, was not shaped as expected. Uranus seemed to have gravity from an unseen planet tugging on it.

Astronomers John Coach Adams and Urbain-Jean-Joseph Le Verrier both made their own mathematical predictions for where this unseen planet would be in the sky.

Neptune was found on September 23, 1846 by Johann Gottfried Galle and his assistant, Louis d'Arrest, based on the mathematical predictions!



(Image Credit: NASA/JPL-Caltech, Voyager)

Neptune is named for the Roman god of the Sea.

The Search for Planets Around Other Stars:
The Problem of Distance

- *What star is closest to the Sun, and at a real distance of 40,000 billion km?*

Alpha Centauri (or Proxima Centauri, the smallest and closest star in the Alpha Centauri system.)

- *How far away would it be on a model with a 1:10 billion scale? (Hint: think about the Stellar Distances activity.)*

On a model with a 1:10 billion scale the model Sun and model Alpha Centauri would be about 4,000 km (or 2,500 miles) apart. This is about the distance between San Francisco and New York, or the width of the continental United States.

If your students have not done the Stellar Distances activity, ask them how far away they think the nearest star to the Sun would be on a model with a scale factor of 1:10 billion.

- *How many AU away from the Sun is Alpha Centauri?*

The distance between the Sun and the Alpha Centauri System is 40,000 billion km, or 40,000,000 million km. Dividing 40,000,000 million km by 150 million km per AU gives a distance of about 270,000 AU.

- *What object can be used to represent the Earth on a model with a scale factor of 1:10 billion? (Hint: Think about the Scale Model Solar System activity.)*

In several of the activities in Stars and Planets, a candy sprinkle has been used to represent the Earth. If your students have not done any of these activities, have them use the diameter of the Earth from Table 1 to calculate a scaled size and then suggest objects that are close to the correct size.

Now, imagine standing on a scale model on a 1:10 billion scale that includes both the solar system and the Alpha Centauri star system.

- *If you were to stand at the model of Alpha Centauri and look back at the model Sun and planets, how hard would it be to see the Earth?*

The answer to this question is that seeing the model Earth would be extremely difficult, and may even seem impossible! A way to think put this problem in perspective is:

Trying to see the Earth from Alpha Centauri is like trying to see a candy sprinkle on a donut in New York when you are standing in San Francisco!

Discovery of Pluto

In 1915, American Percival Lowell predicted a ninth planet, based on the differences between calculated and observed orbits of Neptune and other planets. Although these calculations turned out to be wrong, without them Pluto might not have been discovered until much later!

Astronomer Clyde Tombaugh, at the Lowell Observatory in Flagstaff, Arizona, began an exhaustive search for "Planet X". In 1930, 84 years after Neptune's discovery, Tombaugh discovered Pluto.

Pluto was named in a contest for school children across the country.

Due to Pluto's size and orbit in a part of the solar system known as the Kuiper Belt, it is now considered a dwarf planet.

The vast distances between the stars, and the relatively insignificant sizes of planets, present a major problem in the search for extrasolar planets. However, size and distance are not the only difficulties astronomers face when they look for planets around other stars.

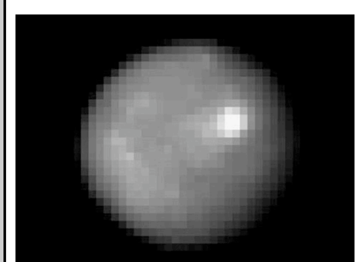
The Problem of Brightness:

Stars are incredibly bright. The brightness of stars is the only reason we can see any stars other than the Sun without the aid of telescopes. Our own star puts out as much light as four trillion trillion hundred-Watt light bulbs!

(In scientific notation, four trillion trillion is 4×10^{24})

Stars are much larger than planets, but their larger size pales in comparison with the distances between them. Even with the best telescopes, most stars are visible as nothing more than points of light. Two exceptions are the Sun, and the red supergiant Betelgeuse.

Did you know? *Ceres, the largest object in the asteroid belt, was briefly classified as a planet after its discovery in 1801.*



(Image credit: NASA/HST, ESA, J. Parker (SwRI) et al.)

Unlike stars, planets are visible only because of the light they reflect from their star. Because stars are so bright, and planets are so dim, planets can easily be lost in the glare of their star.

Demonstration:

Here is where you will use the lamp and the black cards with the blue and white candy sprinkles. If the students have already done the Scale Model Solar System activity or Sizes of Stars, show them the grapefruit or 14 cm yellow ball that represents the Sun. Tell them that for the purposes of this demonstration, the light bulb will represent the model Sun instead of the grapefruit/ball, and that once again the blue candy sprinkle will represent the Earth.

1. Prepare your classroom to be as dark as possible with the lights off.
2. Set up the lamp in one corner of the room, and turn it on, and turn off the room lights.
3. Ask a student to hold the card with the blue candy sprinkle up so that it can reflect the light of the bulb and the other students will be able to see it. It is unlikely that you will be able to put the candy sprinkle and the lamp 15 meters apart (which represents the Earth-Sun distance of a scale of 1:10 billion). Just put them as far apart as possible (preferably with the candy sprinkle in the darkest part of the classroom).
4. If your students have done the Scale Model Solar System activity, ask them if they how far apart the model Sun and model Earth should be if the scale factor is 1:10 billion. (The answer is 15 m.)
5. Next, talk about how much easier it is to see the light bulb than the candy sprinkle.
6. Ask another student to hold the card with the white candy sprinkle next to the card with the blue candy sprinkle. The white candy sprinkle is easier to see than the blue one because it reflects more light, but it is still much harder to see than the light bulb.

When the light is on one side of the room, and the candy sprinkle is on the other side, the situation is more similar to searching for Uranus, Neptune, and the dwarf planets in our own solar system than it is searching for other stars. When astronomers look for planets around other stars, the planet and the star will be very close together in the sky. That is because the distances between the planets and their stars are much, much smaller than the distances between stars.

To roughly simulate this problem, bring the card with the white candy sprinkle as close to the light bulb as possible without blocking the light bulb.

Ask the students: How much harder is it to see the candy sprinkle?

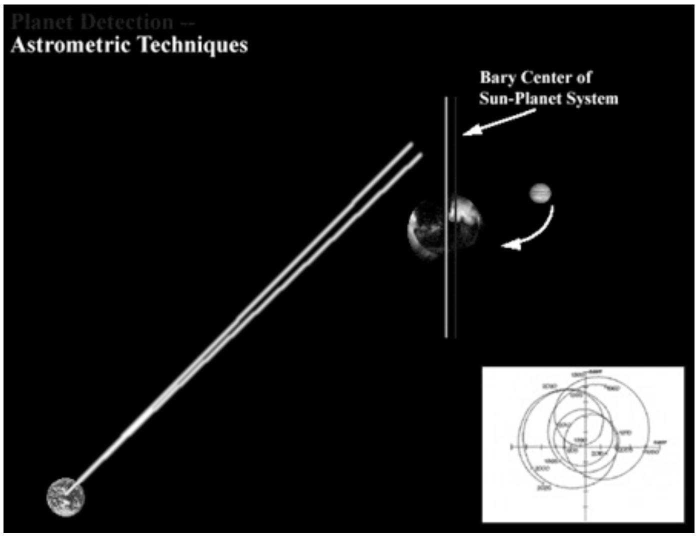
Although the model planet reflects more light when it is closer to the light source, it will be lost in the glare from the unfrosted bulb much in the way a real planet is lost in the glare of its star.

Summarizing the Problem:

Actually seeing a planet around another star is an extremely hard problem. The size of even the largest planets is almost nothing compared with the vast distances between stars. Stars are very bright and planets are relatively dim. However, despite the difficulties involved, astronomers from all around the world have been willing to tackle the problem and have come up with some very clever ways to find extrasolar planets. Most of the techniques astronomers are using to hunt for new planets involve indirect evidence; they are looking for the tiny effects that a planet has on the star it orbits.

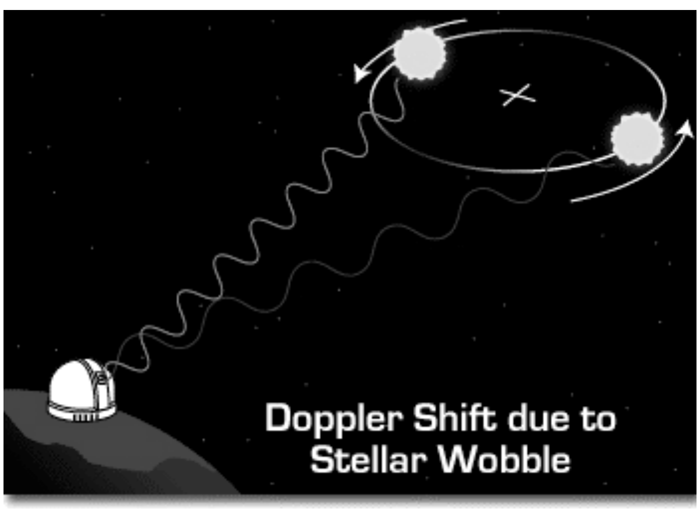
Methods of Detecting Extrasolar Planets

Astrometry



(Image Courtesy NASA/JPL-Caltech)

Radial Velocity Search



(Image Courtesy NASA/JPL-Caltech)

Finding a Planet without "Seeing" it:

Astronomers have come up with ways of finding extrasolar planets by using the light of the stars planets orbit instead of using the light reflected by the planets.

A Matter of Gravity:

Planets have mass and therefore also have gravity that pulls on the matter around them, just as the Earth's gravity pulls on us. Stars, however, have much more mass than planets do. The ability of a planet's gravity to move a star is extremely small in comparison with the star's ability to move the planet. As a planet orbits its star, it causes the star to move with it or "wobble" by a very slight amount. Astronomers can detect the wobble of a star caused by a planet in two different ways. They can look at extremely small changes in the position of a star in the sky with very sensitive instruments in a technique called ***Astrometry****.*

Using another method, called a ***Radial Velocity Search*** *or* ***Doppler Spectroscopy****, astronomers look for a slight shift in the color of the star. If a star is pulled away from us it will look redder, and if it is pulled toward us it will look more blue. This is called Doppler shift.*

For more on planet hunting methods, including an interactive explanation, see http://planetquest.jpl.nasa.gov/science/finding_planets.cfm

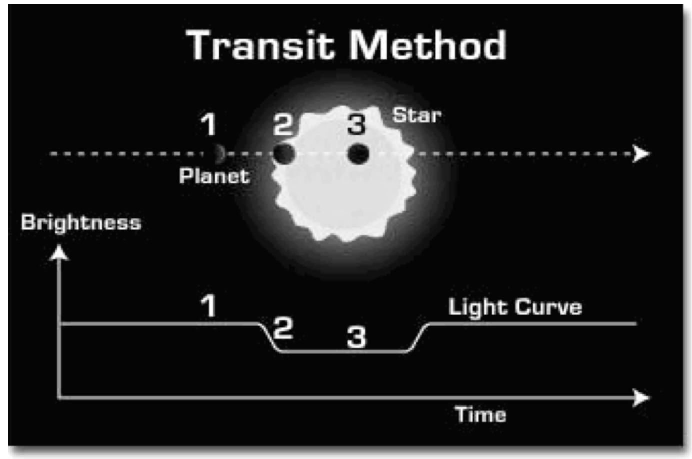
Optional Demonstration:

To model the Doppler shift caused by a planet pulling on a star using sound instead of light, attach a noisemaker to the end of a string and spin the noisemaker around. It doesn't matter what type of sound the noisemaker creates, as long as it is loud and makes a constant pitch. An inexpensive battery-powered buzzer is a good noisemaker, and can be put inside a tennis ball. When you spin the noisemaker so that it moves closer to your students and then farther away from them, they will hear the pitch rise and fall. The frequency of sound they hear is Doppler shifted, much like the light of a star wobbling from the pull of an unseen planet.

Blocking the Light:

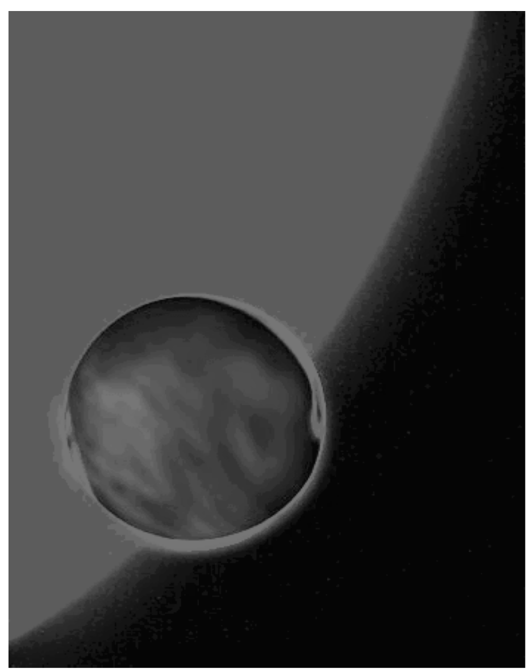
Sometimes astronomers may be fortunate enough to see a planet pass between the Earth and the star the other planet orbits. When our moon passes between the Earth and the Sun, and the Earth, Moon, and Sun are lined up just right, we see a solar eclipse. The Moon is able to block out most of the Sun's light because it is so close to us. Even though the Sun is much bigger than the Moon, the Moon is so close that it and the Sun appear to be about the same size in our sky. When Mercury or Venus passes directly between the Earth and the Sun, we call this event a ***transit*** *rather than an eclipse. This is*

Transit Method



(Image courtesy: NASA/JPL-Caltech)

Orbiting the sun-like star, X0-1, a planet has been discovered with the transit method by a team of amateur astronomers. Planet X0-1b has 0.9 times the mass of Jupiter and an orbit period of 4 days. During the transit it eclipses about 2% of the stars brightness. It is located in the constellation of Corona Borealis. It is located 600 light-years away from us.



(Artist Conception Courtesy: NASAESA/STScl) *because such a small percentage of the Sun's light is blocked out by Mercury or Venus. Transits by extrasolar planets also block out a small amount of their star's light. Astronomers can find planets using the* ***Transit Method*** *by carefully measuring the light we receive from a star.*

Demonstration:

Turn on the lamp and turn back on the lamp. Pass the candy sprinkle taped to the end of a toothpick in front of the light bulb to demonstrate the decrease in the light received from a star during a transit by a planet. The difference in the amount of light the students see should be unnoticeable.

Other Methods:

One method for finding planets that is not discussed in this lesson are the gravitational microlensing - the bending of light rays by a massive object, such as a star. If an unseen planet passes in front of a star acting as a gravitational lens to a background object, the stars rays may further be bent a bit more because of the added mass of the planet. Gravitational microlensing is a difficult concept for middle school children, and so has not been included in the student materials. More information on the technique is available: at JPL's PlanetQuest web site: http://planetquest.jpl.nasa.gov/science/finding_planets.cfm.

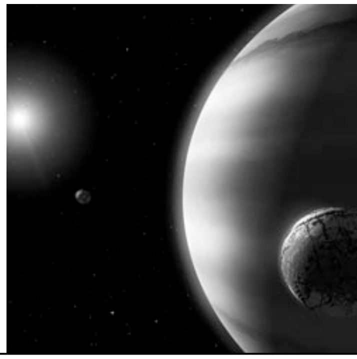
Part 2:

In the second part of Planet Hunting students will be introduced to actual planets astronomers have found orbiting distant stars and NASA's future space-based missions designed to detect Earth-sized planets.

The masses of planets found so far are usually not well known. Most planets that had been found as of 2007 were detected using the radial velocity method. Both that method and astrometry depend on the star moving relative to our line of site.

A hula hoop can be used to demonstrate an orbital plane of a planet around a star. If the plane of the orbit is parallel to our line of site (the hula hoop should be held parallel to the floor for this demonstration), then the planet will pull the star very slightly toward and away from us as it orbits. The mass we measure assumes the planet is in this optimum viewing geometry, and so gives us the minimum mass for the planet. This orbital orientation works best for Doppler spectroscopy.

If the planet's orbit around its star is perpendicular to our line of sight (the hula hoop held straight up and down facing the class), then the planet will not pull the star toward or away from us. This orientation does not work for Doppler spectroscopy, but is idea for astrometry.



Artist Conception Courtesy NASA/JPL-Caltech

Artist's conception of an extrasolar gas giant. planet

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- How and when were the outermost planets in our own solar system discovered?
- What are the problems in hunting for other (extrasolar) planets?
- How can astronomers find a planet without really "seeing it"?

Planet Hunting 1: Finding Planets

The Discovery of Planets in Our Own Solar System:

Civilizations across the globe have known of Mercury, Venus, Mars, Jupiter, and Saturn since ancient times. The two outermost planets, and the dwarf planets, were all discovered in the past few centuries, and with the aid of telescopes. Before Uranus was discovered, astronomers didn't expect to find any planets other than the five visible with the unaided eye and the Earth. *Why are Uranus and Neptune harder to see from the Earth than the other five planets? Why wasn't Pluto discovered until the 20th century?*

Comparing the sizes and distances of the planets will help you answer these questions. The diameters and average distances from the Sun for the planets in our solar system are given in Table 1. An easy way to compare average distances between the planets is to look at them in terms of the Earth-Sun distance, which is called an **Astronomical Unit**. The symbol for an Astronomical Unit is **AU**.

Discovery of Uranus

Uranus was discovered in 1781 by musician and amateur astronomer William Herschel. Uranus was the first planet not known about by ancient people all over the world.

While observing the constellation of Gemini with a homemade telescope, Herschel discovered a unique object that didn't act like a star or a comet. After carefully recording his observations over several years, Hershel was able to show that he had found a new planet!

Uranus was named after the Greek god of the sky.

For Tables 1 and 2 complete the last columns with distances in AU using the given distance from the Sun in kilometers for each planet or dwarf planet.

Table 1: Planets in Our Solar System

Planet	Date Discovered	Diameter	Distance from Sun	Distance from Sun in AU
Mercury	Ancient Times	4,878 km	58 million km	
Venus	Ancient Times	12,104 km	108 million km	
Earth	-----	12,756 km	150 million km	1.0
Mars	Ancient Times	6,794 km	228 million km	
Jupiter	Ancient Times	142,796 km	778 million km	
Saturn	Ancient Times	120,660 km	1,427 million km	
Uranus	1781	51,118 km	2,871 million km	
Neptune	1846	54,523 km	4,497 million km	

Table 2: Dwarf Planets in Our Solar System

Planet	Date Discovered	Diameter	Distance from Sun	Distance from Sun in AU
Ceres	1801	950 km	441 million km	
Pluto	1930	2,300 km	5,913 million km	
Eris	2003	2,400 km	10,150 million km	

What about planets orbiting other stars?

Planets orbiting other stars (**extrasolar planets**) are much harder to find than planets in our own solar system. The first such planet orbiting another normal main sequence star or giant star wasn't discovered until 1995!

The Search for Planets Around Other Stars:
The Problem of Distance

- What star is closest to the Sun, and at a real distance of 40,000 billion km?

- How far away would it be on a model with a 1:10 billion scale? *(Hint: think about the Stellar Distances activity.)*

- How many AU away from the Sun is Alpha Centauri?

- What object can be used to represent the Earth on a model with a scale factor of 1:10 billion? *(Hint: Think about the Scale Model Solar System activity.)*

Now, imagine standing on a scale model on a 1:10 billion scale that includes both the solar system and the Alpha Centauri star system.

- If you were to stand at the model of Alpha Centauri and look back at the model Sun and planets, how hard would it be to see the Earth?

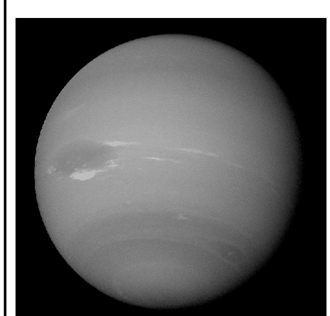
The vast distances between the stars, and the relatively insignificant sizes of planets, present a major problem in the search for extrasolar planets. *However, size and distance are not the only difficulties astronomers face when they look for planets around other stars.*

The Discovery of Neptune and the Power of Math!

Astronomer's began the hunt for Neptune because Uranus' orbit, its path around the Sun, was not shaped as expected. Uranus seemed to have gravity from an unseen planet tugging on it.

Astronomers John Coach Adams and Urbain-Jean-Joseph Le Verrier both made their own mathematical predictions for where this unseen planet would be in the sky.

Neptune was found on September 23, 1846 by Johann Gottfried Galle and his assistant, Louis d'Arrest, based on the mathematical predictions!



(Image Credit: NASA/JPL-Caltech, Voyager)

Neptune is named for the Roman god of the Sea.

Discovery of Pluto

In 1915, American Percival Lowell predicted a ninth planet, based on the differences between calculated and observed orbits of Neptune and other planets. Although these calculations turned out to be wrong, without them Pluto might not have been discovered until much later!

Astronomer Clyde Tombaugh, at the Lowell Observatory in Flagstaff, Arizona, began an exhaustive search for "Planet X". In 1930, 84 years after Neptune's discovery, Tombaugh discovered Pluto.

Pluto was named in a contest for school children across the country.

Due to Pluto's size and orbit in a part of the solar system known as the Kuiper Belt, it is now considered a dwarf planet.

The Problem of Brightness:

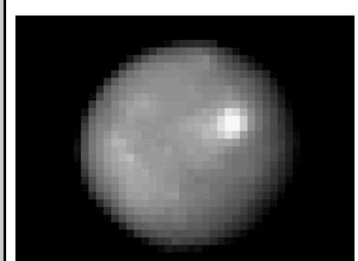
Stars are incredibly bright. The brightness of stars is the only reason we can see any stars other than the Sun without the aid of telescopes. *Our own star puts out as much light as four trillion trillion hundred-Watt light bulbs!* Stars are much larger than planets, but their larger size pales in comparison with the distances between them. Even with the best telescopes, most stars are visible as nothing more than points of light. Two exceptions are the Sun, and the red supergiant Betelgeuse.

Unlike stars, planets are visible only because of the light they reflect from their star. Because stars are so bright, and planets are so dim, planets can easily be lost in the glare of their star.

Summarizing the Problem:

Actually seeing a planet around another star is an extremely hard problem. The size of even the largest planets is almost nothing compared with the vast distances between stars. Stars are very bright and planets are relatively dim. However, despite the difficulties involved, astronomers from all around the world have been willing to tackle the problem and have come up with some very clever ways to find extrasolar planets. Most of the techniques astronomers are using to hunt for new planets involve indirect evidence; they are looking for the tiny effects that a planet has on the star it orbits.

Did you know? *Ceres, the largest object in the asteroid belt, was briefly classified as a planet after its discovery in 1801.*



(Image credit: NASA/HST, ESA, J. Parker (SwRI) et al.)

Finding a Planet without "Seeing" it:

Astronomers have come up with ways of finding extrasolar planets by using the light of the stars planets orbit instead of using the light reflected by the planets.

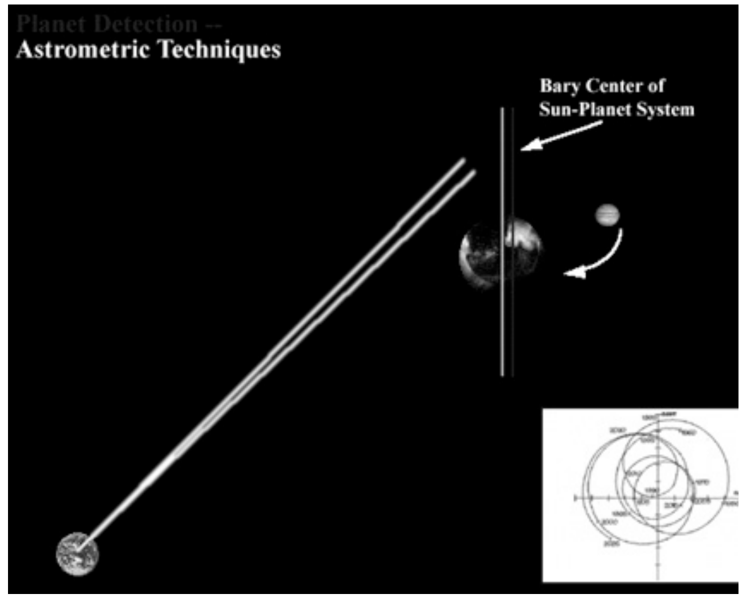
A Matter of Gravity:

Planets have mass and therefore also have gravity that pulls on the matter around them, just as the Earth's gravity pulls on us. Stars, however, have much more mass than planets do. The ability of a planet's gravity to move a star is extremely small in comparison with the star's ability to move the planet. As a planet orbits its star, it causes the star to move with it or "wobble" by a very slight amount. Astronomers can detect the wobble of a star caused by a planet in two different ways. They can look at extremely small changes in the position of a star in the sky with very sensitive instruments in a technique called **Astrometry**.

Using another method, called a **Radial Velocity Search** or **Doppler Spectroscopy**, astronomers look for a slight shift in the color of the star. If a star is pulled away from us it will look redder, and if it is pulled toward us it will look more blue. This is called *Doppler shift*.

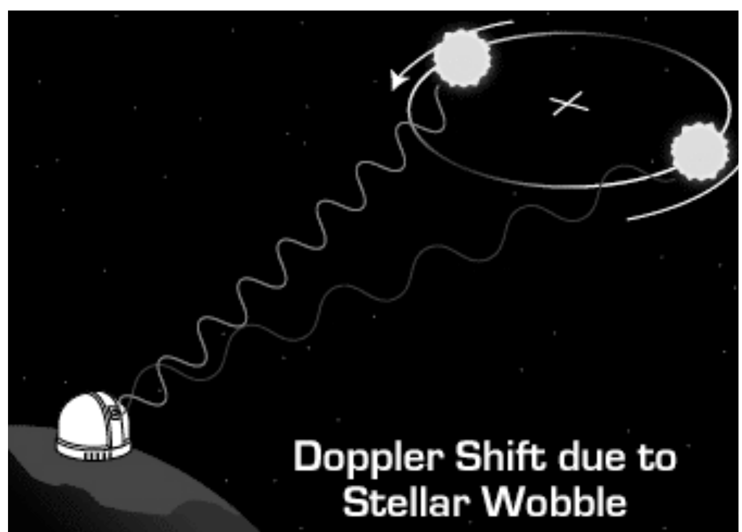
Methods of Detecting Extrasolar Planets

Astrometry



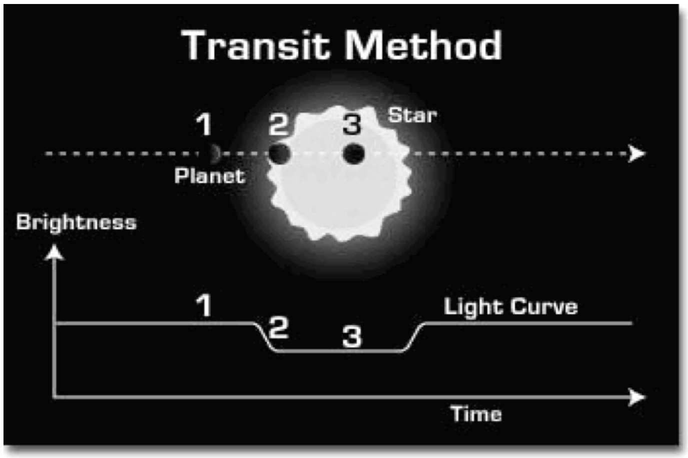
(Image Courtesy NASA/JPL-Caltech)

Radial Velocity Search



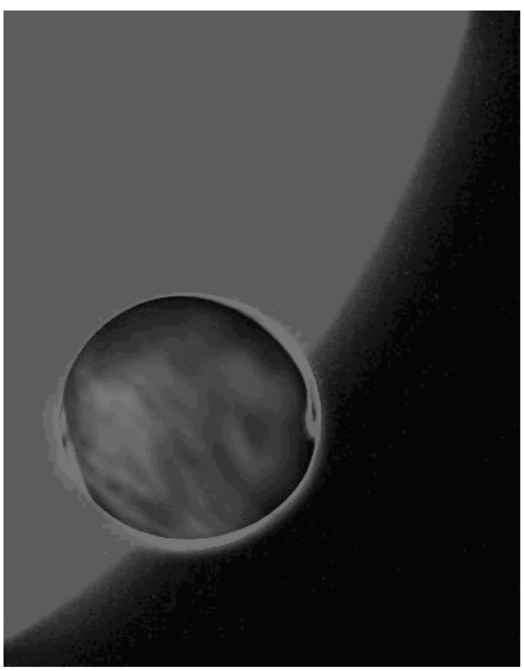
(Image Courtesy NASA/JPL-Caltech)

Transit Method



(Image courtesy: NASA/JPL-Caltech)

Orbiting the sun-like star, X0-1, a planet has been discovered with the transit method by a team of amateur astronomers. Planet X0-1b has 0.9 times the mass of Jupiter and an orbit period of 4 days. During the transit it eclipses about 2% of the stars brightness. It is located in the constellation of Corona Borealis. It is located 600 light-years away from us.

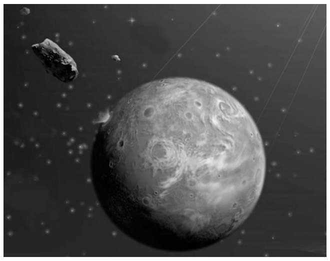


(Artist Conception Courtesy: NASAESA/STScI)

Blocking the Light:

Sometimes astronomers may be fortunate enough to see a planet pass between the Earth and the star the other planet orbits. When our moon passes between the Earth and the Sun, and the Earth, Moon, and Sun are lined up just right, we see a solar eclipse. The Moon is able to block out most of the Sun's light because it is so close to us. Even though the Sun is much bigger than the Moon, the Moon is so close that it and the Sun appear to be about the same size in our sky. When Mercury or Venus passes directly between the Earth and the Sun, we call this event a **transit** rather than an eclipse. This is because such a small percentage of the Sun's light is blocked out by Mercury or Venus. Transits by extrasolar planets also block out a small amount of their star's light. Astronomers can find planets using the **Transit Method** by carefully measuring the light we receive from a star.

Earthlike Extrasolar Planet



(Artist conception, Courtesy: NASA/JPL-Caltech Planetquest).

In this Exploration, find out:

- *What planets have been found around other stars?*
- *How does our own solar system compare to the newly found planetary systems?*
- *What are the limitations of current and planned planet hunting efforts?*

Planet Hunting 2: New Discoveries Teacher Guide

In this lesson, Part 2 of Planet Hunting, students will be introduced to planetary systems astronomers have found around other stars, make scale models of some of these systems, and compare them to our solar system. Students will also learn about exciting new technologies designed to help astronomers find Earth-like planets in the future. The lesson builds upon the other activities in the *Stars and Planets* program, especially the Scale Model Solar System, Sizes of Stars, and Stellar Distances activities, and is intended to follow Planet Hunting Part 1.

Recommend Prerequisites: Planet Hunting Part 1, Scale Model Solar System, Sizes of Stars, Stellar Distances, and Lifetimes of Stars

Grade Level: 6-8

Curriculum Standards: The Death 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)

Time Frame: The activity should take approximately 45 minutes to 1 hour to complete, including a short introduction and follow-up. Reading may be assigned as homework or given in class.

Purpose: To increase student awareness of the cutting-edge science of the hunt for extrasolar planets and compare planetary systems around other stars with our own solar system.

Key concepts:

- The first planet orbiting another normal star was discovered in 1995, and hundreds more have since been found.
- Many of the Jupiter-sized planets around other stars are at very different distances from their stars compared with the distance between the Sun and Jupiter. Some are much closer to their star than any planet in our solar system is to the Sun.
- Earth-like planets are much harder to find than Jupiter-like planets.
- The number of known extrasolar planets is constantly growing.
- Dozens of efforts to find extrasolar planets are currently underway or being planned. Some of these efforts use telescopes here on Earth and some will use telescopes in space. NASA's Kepler and Terrestrial Planetfinder missions will focus on finding Earth-sized planets around normal stars.

Supplies for Planet Hunting Part 2:

- A copy of the student handout for part 2 for each student
- A copy of Table 3: A Sampling of Extrasolar Planets (with or without all of the columns filled in)
- Three marbles (to represent Jupiter-like planets), and three peppercorn or corn kernel (to represent a Neptune-like planet)*
- Two candy sprinkles taped to index cards to represent Earth-like planets
- One grapefruit or 14 cm yellow ball (for a Sun-like Star)*
- One orange (for a K class star)*
- One cherry tomato or small red ball (for a M class star)*
- One cantaloupe (for a F class star)*
- A calculator for each student*

* Objects should be the same or similar to those used in the Scale Model Solar System and Sizes of Stars activities.

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

Introduction:

Start the activity by asking the students introductory questions.

- Which type of planet do you think will be easier to find around another star: an Earth-like planet or Jupiter-like planet?

- Do you know about any of the recently discovered planets around other stars?

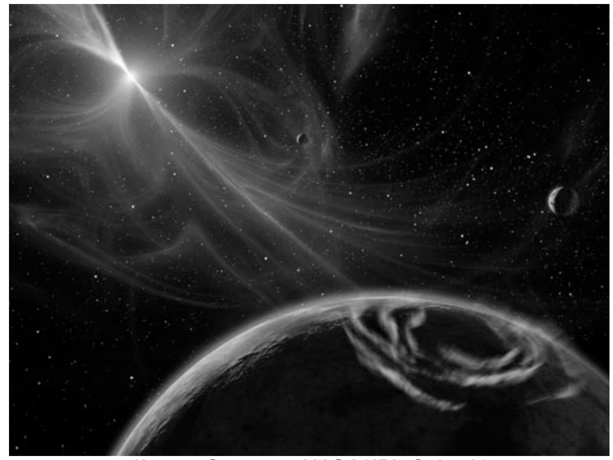
If the students read the information sheet on their own, discuss what they learned as a class. Each of your students also need a copy of Table 3 (with or without the last column filled in) as a reference.

Extrasolar Planet Discoveries

The very first planet found outside of our solar system was discovered in 1992 orbiting the core of a "dead" high-mass star - a type of neutron star called a ***pulsar****. Pulsars send beams of radio waves into space regular basis, and like a lighthouse, the rotation of the pulsar causes the beams to sweep across space. A pulsar seems to switch on and off as the beams of light it produces sweep by. Orbiting planets will cause small changes in the timing of the pulses of light that can be measured by radio telescopes on the Earth.*

Planets around pulsars are easier to find than planets around normal stars. Even planets the size of Earth's moon have enough gravity to pull on a pulsar enough to make a noticeable change in the timing of pulsar pulses. The three planets orbiting pulsar PSR B1257+12 are small and may be similar to the Earth in terms of their mass. But the planetary system is very different from our solar system. Before PSR 1257+12 became a neutron star, it was a very massive star that went supernova! Any planets that orbited the star before the violent end of its life as a normal star are unlikely to have survived. The planets orbiting the pulsar probably formed from debris left behind after the original star went supernova.

Pulsar Planets



(Image Courtesy: NASA/JPL-Caltech)

This image is an artist's conception of the pulsar planet system discovered by Aleksander Wolszczan in 1992. Pulsar planets may form much the way other planets do – from disks of gas and dust circling a star. In the case of pulsar planets, however, the gas and dust are debris left over from the supernova of a massive star. And the star these planets orbit is the collapsed core of the star that exploded.

The term "extrasolar planet" literally means a planet outside our solar system.

First Planet around a Sun-Like Star

In 1995, astronomers M. Mayor and D. Queloz announced the discovery of the first extrasolar planet orbiting a Sun-like star called 51 Pegasi or just 51 Peg. The planet was nothing like what was expected! Most planetary scientists had assumed astronomers would find extrasolar planets that were very similar to planets in our own solar system. The planet orbiting 51 Peg, however, is very strange. It is a Jupiter-like planet, but is only 0.05 AU away from its star. (How far away is Jupiter from our own star, the Sun?)

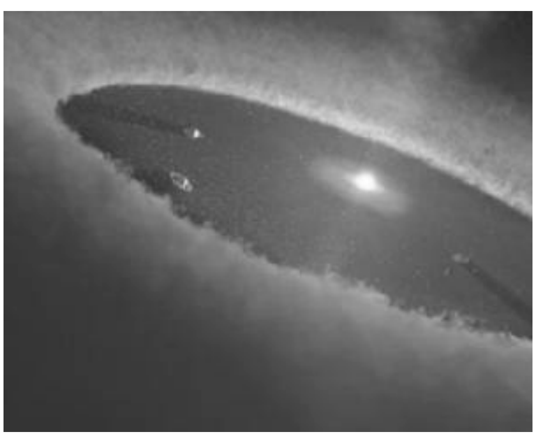
Note: Roughly speaking, since main sequence G class stars have similar masses, differences in masses between different G class stars can be ignored when comparing orbit times (or planetary years). Orbit times for planets around other G-class stars will scale with the average distance of the planets from their star. Some astronomers classify 51 Pegasi, or 51 Peg for short, as a main sequence G-class star. Others classify 51 Peg as yellow subgiant, a sun-like star in the process of dying. Whichever is the proper classification for 51 Peg, the distinction is unnecessary for students at the middle school level.

Even More Planets Found

Using clever techniques and careful observations astronomers had found more than 250 planets orbiting other stars by September 2007. Many more have probably been found by the time you read this. Most of the 250+ planets have been discovered with the method called a Radial Velocity Search, and at least one planet has also been "seen" by the Transit Method. Table 3 contains a sampling of some of the planetary systems that have been discovered around normal main sequence stars. Some planetary systems are known to have multiple planets. By 2007, most of the objects found orbiting nearby main sequence stars are Jupiter-like planets and some failed stars called ***brown dwarfs.*** *As telescopes and observing techniques improve, astronomers are finding smaller planets.*

Planet Formation

Planets are believed to grow from the solid material in a disk around a young star.



(Image courtesy: *NASA/JPL-Caltech)*

Artist's conception: Planets sweep away a clearing in mass of dust surrounding a fledgling star.

The exact definitions of brown dwarfs and giant planets are unclear. Almost all of the planetary systems look very different from our solar system. Some scientists use a set mass, usually around 10 times of the mass of Jupiter, as the dividing line between planets and brown dwarfs. Other scientists distinguish a planet from a brown dwarf based on how it formed. Planets are believed to grow from the solid material in a disk around a young star. *(This process of planet formation is called accretion).* Once a planet is massive enough, it can capture and hold on to gas in the disk. If a planet is able to hold add enough gas it will become a giant planet like Jupiter. In contrast, brown dwarfs are believed to form the way stars do - from the collapse of part of an interstellar cloud of dust and gas. Giant planets may also form from gas collapsing in the disks of gas and dust that circle many young stars. Currently, astronomers disagree on how to classify objects that are many times the mass of Jupiter but which are not massive enough for fusion to begin in their cores.

In 2005, the Earth-like first planet orbiting another main sequence star was found. The planet, Gliese 876 d, is more about 7.5 times more massive than the Earth. The rocky planet orbits its small M class star at a distance equal to only about 1/50th of the Earth-Sun distance. In 2007, two planets about the same size were found around another small M class star, Gliese 581. Both of these planets are closer to their star than Mercury is to our hotter and brighter sun. At the time of this writing, scientists are debating the probability that one or both of these two planets might have the right surface temperature for liquid water!

Gliese 581 c is about five times as massive as the Earth, and Gliese 581 d is about eight times as massive. Consider asking your students to imagine how life on those planets might be different from life on Earth.

- *Look at Table 3. How do the distances of extrasolar planets from their star compare with the distances between the Sun and the Earth and the Sun and Jupiter? (Part 1, Table 1 may help you answer this question.)*

When comparing Tables 1 and 3, it should be obvious that the distances between the planets and star in our own solar system are generally much larger. The planet discovered around 51 Pegasi orbits 20 times closer to its G-class star than the Earth does around the Sun. Jupiter, the closest giant planet to the Sun, orbits than 100 times further away from its star than does the planet orbiting 51 Peg! Many of the extrasolar planets that have been discovered so far are in similar orbits to 51 Peg's planet, with a few even closer to their stars. Several others, especially in planetary systems with multiple planets, have distances that would place them between the Earth and Jupiter if they were in our own solar system.

Comparing Other Planetary Systems with the Solar System

There is only one solar system, but astronomers now know that the solar system is only one of many planetary systems in our part of the galaxy. The first extrasolar solar planets discovered around other normal stars are closer to their stars than Jupiter is to the Sun, and many are closer than the Earth is to the Sun. These planets are often referred to as "hot Jupiters". Some of these planets are so close to their star, and only take three days to complete an orbit! Mercury, which takes 88 days to complete an orbit, has the shortest year of any planet in our own solar system. Astronomers are now finding Jupiter-like planets in orbits that resemble Jupiter's orbit around the Sun, but most planetary systems found so far are very different from our own.

Astronomers don't know yet how typical the recently discovered planetary systems are, or whether or not our own solar system is typical. Large, massive, Jupiter-like planets are much easier to find than Earth-like planets. Techniques that depend on the effect the gravity of a planet has on its star are also more likely to find planets that orbit close to their stars. The more mass a planet has, and the closer it is to its star, the stronger pull of the planet's gravity on the star will be.

Many extrasolar planets have been found around Sun-like G-class stars. Astronomers aren't able to search for planets around every star in the solar neighborhood. Instead, they must choose what stars to observe.

- *Why do you think that astronomers may have chosen more Sun-like stars than other classes of stars?*

Your students may come up with several answers to this question. If they have done the Lifetimes of Stars activity then they may bring up the search for life and lifetimes of stars. Some types of stars are also more common than others (see the Star Birth activity). Other motivations for focusing on Sun-like stars include looking for "twins" of our own solar system that may have habitable Earth-like planets, and limitations of detection methods. Doppler Spectroscopy, for example, can only be used with main sequence stars of classes M through F, and some types of giant stars.

Activity: Scale Models of Other Planetary Systems

We can make scale models of other planetary systems and compare them directly with our own solar system.

- *First, complete the last column of Table 3 with distances using the 1:10 billion scale factor also used to make the Scale Model Solar System.*

Your students may not realize how simple conversion from AU to scaled meters can be if they remember that 1 AU (the Earth-Sun distance) in the real solar system is equal to 15 m in the Scale Model Solar System. All the students need to do is multiple each of the distances in AU by 15 m/AU to get the number of meters for the last column of the table.

- *Using our scale model objects from previous activities construct scale models of all the planetary systems in the table.*

When your students have completed Table 3, you are ready to make your scale models. For the models of other planetary systems it is recommended to create selected models as a class so that the teacher can facilitate discussions of the differences and similarities of each planetary system to our own.

You will probably not have sufficient time to model all of the sample planetary systems, but try to pick a few with different types of stars and planets at different distances from the star. Before making the models, you can have your students note beside the column for each planet what object would be appropriate to use.

For planets 0.4 M_J or larger, use the same object used to represent Jupiter in the Scale Model Solar System (marble.) For planets about 0.05 $M_{J,}$ use the same object used to represent Neptune (popcorn kernel or peppercorn). For objects about 0.02 M and smaller (masses in bold in Table 3), these are closer to Earth-sized planets and are probably rocky. Use both the Neptune-sized object and the largest object representing a rocky planet in the Scale Model Solar System (candy sprinkle). Ask students which should be used given that these planets have masses between those of Neptune and the Earth, but are probably rocky.

Sample objects and distances:

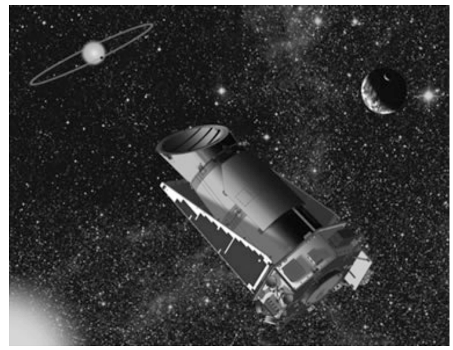
- **51 Pegasi** requires a grapefruit/14 cm yellow ball, 1 marble, and an area 0.75 m long
- **47 Ursa Majoris** requires a grapefruit/14 cm yellow ball, 2 marbles, and an area 112 m long
- **Upsilon Andromedae** requires a cantaloupe, 3 marbles, and an area at least 37.5 m long
- **Gliese 876** requires a 2.5 cm red ball or cherry tomato, 2 marbles, a peppercorn or popcorn kernel, a candy sprinkle taped to a card and an area 3.2 m long
- **Gliese 581** requires a 2.5 cm red ball or cherry tomato, three peppercorn or popcorn kernels, two candy sprinkles taped to index cards, and an area 1.1 m.
- **Epsilon Eridani** requires an orange, 1 marble, and an area at least 49.5 m long
- **HD 82943** requires an orange, 1 marble, and an area at least 0.75 m long

The data on each of these planetary systems is from the Extrasolar Planet Encyclopaedia (http://exoplanets.org) an informational web site for professional astronomers maintained by Jean Schneider (CNRS-LUTH, Paris Observatory). The search for extrasolar planets is a cutting-edge and dynamic field of science and the Extrasolar Planet Encyclopaedia is constantly updated with new information from the astronomical community.

Searching for Earth-like Planets:

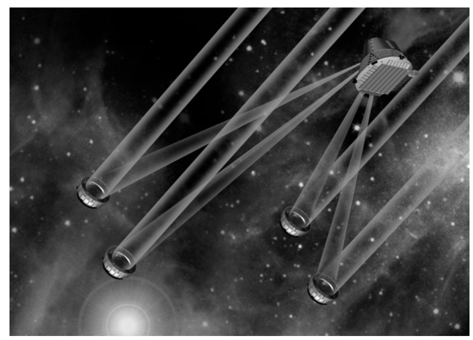
Dozens of planned and current efforts are involved in the search for extrasolar planets. Astronomers use telescopes here on Earth now and in the future plan to continue those "ground-based" efforts and also use new telescopes in space. Some of the most exciting planned missions will have the goal of finding Earth-like planets around other stars.

Kepler Mission



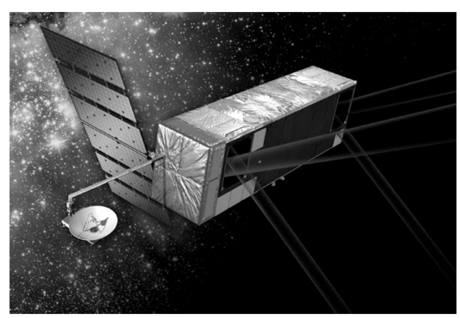
*The **Kepler mission** was selected by NASA for to look for small rocky planets from Earth orbit using the Transit method. One of Kepler's goals following its 2009 launch will be to find out if Earth-like planets are common in the solar neighborhood. Check out the Kepler Web site (http://www.kepler.arc.nasa.gov/) for more information on this exciting mission.*

Terrestrial Planet Finder



*Another NASA mission to find Earth-like planets, the **Terrestrial Planet Finder** (http://tpf.jpl.nasa.gov), is currently in the planning phase. Terrestrial Planet finder will actually have the capability to image Earth-like planets around other stars and find out information about the atmospheres of those planets that could tell scientists if other Earth-like planets are capable of supporting life. To accomplish its task, the Terrestrial Planet Finder will use four extremely light-sensitive telescopes orbiting the Earth together and a technique called **interferometry** to reduce the glare of parent stars a factor of more than one hundred-thousand to see planetary systems as far away as 50 light years. The mission will also study disks around forming stars to help astronomers better understand how planets form.*

SIM PlanetQuest



***SIM PlanetQuest** (formerly called Space Interferometry Mission), currently under development by NASA and Jet Propulsion Laboratory, will determine the positions and distances of stars several hundred times more accurately than any previous program. This accuracy will allow SIM to determine the distances to stars throughout the galaxy and to probe nearby stars for Earth-sized planets. SIM will open a window to a new world of discoveries. Check out the SIM Planet Quest website (http://planetquest.jpl.nasa.gov/SIM/sim_index.cfm) for more information on this planned mission.*

A list of the projects involved in the search for extrasolar planets is available on the Extrasolar Planet Encyclopaedia Web site at http://exoplanet.eu/searches.php.

Things to Think About:

- *If a planetary system is listed as having one planet does that mean that we know for certain that only one planet is orbiting the star?*

No. In Table 3, it is clear that many of the planets in multi-planet were found years apart from one another. As technology and techniques improve and planet searches gather more data, astronomers are finding new planets, many of which are smaller and/or farther from their stars than the planets that could be found before.

- *Many of the planetary systems that have been found so far, with giant planets very close to their stars, look nothing like our own. Does that mean that solar systems like our own are rare?*

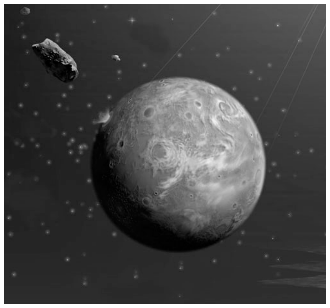
Not necessarily. The planets we have found so far are the planets that are easiest to find with the techniques and technology astronomers currently have at their disposal. The impact of better techniques, technology, and data can be seen in the discovery dates of the smaller planets in Table 3.

- *How might the discoveries of planets around other stars affect the way scientists view the possibility of finding evidence of life on another planet?*

This is really a thought question for the students and doesn't necessarily have a right answer. The fact that we know of planets orbiting other stars makes life elsewhere seem more probable. However, we don't yet know what percentage of Sun-like stars have planetary systems that look like our own, with truly Earth-like planets. If we find that Earth-like planets in orbits similar to our own are common, that would make the possibility of finding evidence for life on another world much more likely.

For more information on the possibility of life on other worlds in our own solar system and beyond, see the resources for teachers provided by NASA's Astrobiology Institute at http://astrobiology.nasa.gov/nai/education-and-outreach/. Excellent resources for middle school include Life on Earth... and Elsewhere? An Educator Resource Guide in Astrobiology, available free of charge for download, and Astro-Venture (also available at http://astroventure.arc.nasa.gov/).

Earthlike Extrasolar Planet



(Artist conception, Courtesy: NASA/JPL-Caltech Planetquest).

In this Exploration, find out:

- What planets have been found around other stars?
- How does our own solar system compare to the newly found planetary systems?
- What are the limitations of current and planned planet hunting efforts?

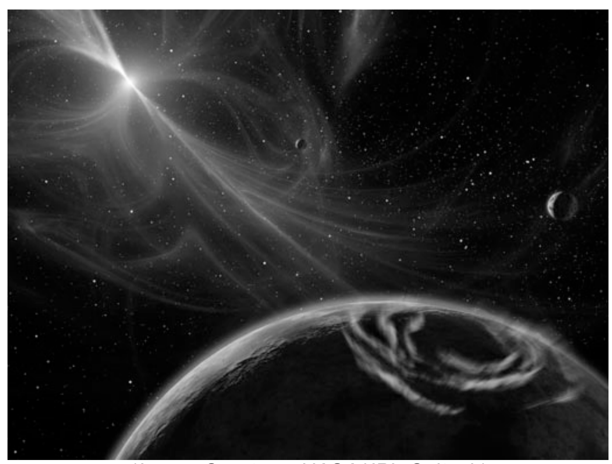
Planet Hunting – New Discoveries

Extrasolar Planet Discoveries

The very first planet found outside of our solar system was discovered in 1992 orbiting the core of a "dead" high-mass star - a type of neutron star called a **pulsar**. Pulsars send beams of radio waves into space regular basis, and like a lighthouse, the rotation of the pulsar causes the beams to sweep across space. A pulsar seems to switch on and off as the beams of light it produces sweep by. Orbiting planets will cause small changes in the timing of these pulses of light that can be measured by radio telescopes on the Earth.

Planets around pulsars are easier to find than planets around normal stars. Even planets the size of Earth's moon have enough gravity to pull on a pulsar enough to make a noticeable change in the timing of pulsar pulses. The three planets orbiting pulsar PSR B1257+12 are small

Pulsar Planets



(*Image Courtesy: NASA/JPL-Caltech)*

This image is an artist's conception of the pulsar planet system discovered by Aleksander Wolszczan in 1992. Pulsar planets may form much the way other planets do – from disks of gas and dust circling a star. In the case of pulsar planets, however, the gas and dust are debris left over from the supernova of a massive star. And the star these planets orbit is the collapsed core of the star that exploded.

and may be similar to the Earth in terms of their mass. But the planetary system is very different from our solar system. Before PSR 1257+12 became a neutron star, it was a very massive star that went *supernova*! Any planets that orbited the star before the violent end of its life as a normal star are unlikely to have survived. The planets orbiting the pulsar probably formed from debris left behind after the original star went supernova.

First Planet around a Sun-Like Star

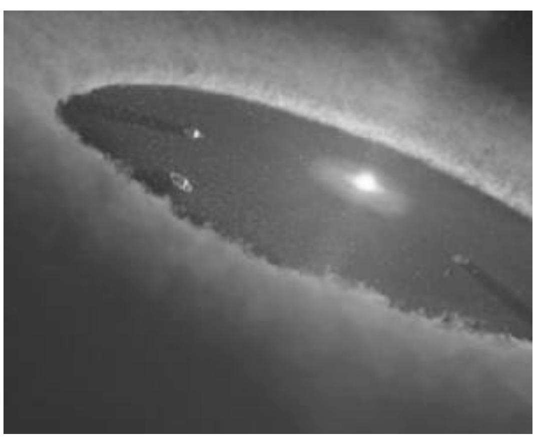
In 1995, astronomers M. Mayor and D. Queloz announced the discovery of the first extrasolar planet orbiting a Sun-like star called 51 Pegasi or just 51 Peg. *The planet was nothing like what was expected!* Most planetary scientists had assumed astronomers would find extrasolar planets that were very similar to planets in our own solar system. The planet orbiting 51 Peg, however, is very strange. It is a Jupiter-like planet, but is only 0.05 AU away from its star. *(How far away is Jupiter from our own star, the Sun?)*

Even More Planets Found

Using clever techniques and careful observations astronomers had found more than 250 planets orbiting other stars by September 2007. Many more have probably been found by the time you read this. Most of the 250+ planets have been discovered with the method called a Radial Velocity Search, and at least one planet has also been "seen" by the Transit Method. Table 3 contains a sampling of some of the planetary systems that have been discovered around normal main sequence stars. Some planetary systems are known to have multiple planets. By 2007, most of the objects found orbiting nearby main sequence stars are Jupiter-like planets and some failed stars called **brown dwarfs.** As telescopes and observing techniques improve, astronomers are finding smaller planets.

Planet Formation

Planets are believed to grow from the solid material in a disk around a young star.



(Image courtesy: *NASA/JPL-Caltech)*

Artist's conception: Planets sweep away a clearing in mass of dust surrounding a fledgling star.

In 2005, the Earth-like first planet orbiting another main sequence star was found. The planet, Gliese 876 d, is more than five times more massive than the Earth. The rocky planet orbits its small M class star at a distance equal to only about 1/50th of the Earth-Sun distance. In 2007, two planets about the same size were found around another small M class star, Gliese 581. Both of these planets are closer to their star than Mercury is to our hotter and brighter sun. At the time of this writing, scientists are debating the probability that one or both of these two planets might have the right surface temperature for liquid water!

- Look at Table 3. How do the distances of extrasolar planets from their star compare with the distances between the Sun and the Earth and the Sun and Jupiter? (*Part 1, Table 1 may help you answer this question.)*

Comparing Other Planetary Systems with the Solar System

There is only one solar system, but astronomers now know that the solar system is only one of many planetary systems in our part of the galaxy. The first extrasolar solar planets discovered around other normal stars are closer to their stars than Jupiter is to the Sun, and many are closer than the Earth is to the Sun. These planets are often referred to as “hot Jupiters”. Some of these planets are so close to their star, and only take three days to complete an orbit! Mercury, which takes 88 days to complete an orbit, has the shortest year of any planet in our own solar system. Astronomers are now finding Jupiter-like planets in orbits that resemble Jupiter’s orbit around the Sun, but most planetary systems found so far are very different from our own.

Astronomers don't know yet how typical the recently discovered planetary systems are, or whether or not our own solar system is typical. Large, massive, Jupiter-like planets are much easier to find than Earth-like planets. Techniques that depend on the effect the gravity of a planet has on its star are also more likely to find planets that orbit close to their stars. The more mass a planet has, and the closer it is to its star, the stronger pull of the planet's gravity on the star will be.

Many extrasolar planets have been found around Sun-like G-class stars. Astronomers aren't able to search for planets around every star in the solar neighborhood. Instead, they must choose what stars to observe.

- Why do you think that astronomers may have chosen more Sun-like stars than other classes of stars?

Scale Models of Other Planetary Systems Activity

We can make scale models of other planetary systems and compare them directly with our own solar system.

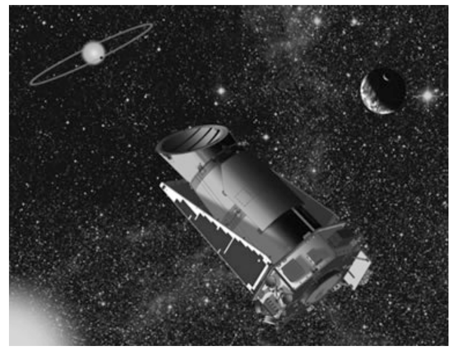
- First, complete the last column of Table 3 with distances using the 1:10 billion scale factor also used to make the Scale Model Solar System.

- Using our scale model objects from previous activities construct scale models of the planetary systems in the table.

Searching for Earth-like Planets:

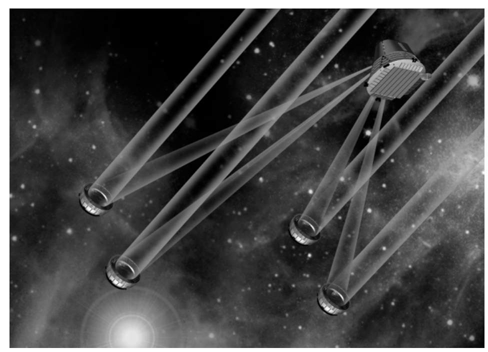
Dozens of planned and current efforts are involved in the search for extrasolar planets. Astronomers use telescopes here on Earth now and in the future plan to continue those "ground-based" efforts and also use new telescopes in space. Some of the most exciting planned missions will have the goal of finding Earth-like planets around other stars.

Kepler Mission



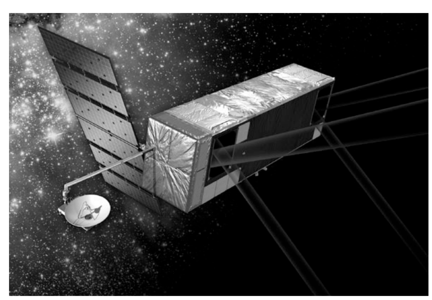
The **Kepler mission** was selected by NASA for a 2005 launch, and will look for small rocky planets from Earth orbit using the Transit method. One of Kepler's goals is to find out if Earth-like planets are common in the solar neighborhood. Check out the Kepler Web site (*http://www.kepler.arc.nasa.gov/*) for more information on this exciting mission.

Terrestrial Planet Finder



Another NASA mission to find Earth-like planets, the **Terrestrial Planet Finder** *(http://tpf.jpl.nasa.gov)*, is currently in the planning phase. Terrestrial Planet finder will actually have the capability to image Earth-like planets around other stars and find out information about the atmospheres of those planets that could tell scientists if other Earth-like planets are capable of supporting life. To accomplish its task, the Terrestrial Planet Finder will use four extremely light-sensitive telescopes orbiting the Earth together and a technique called **interferometry** to reduce the glare of parent stars a factor of more than one hundred-thousand to see planetary systems as far away as 50 light years. The mission will also study disks around forming stars to help astronomers better understand how planets form.

SIM PlanetQuest



SIM PlanetQuest (formerly called Space Interferometry Mission), currently under development by NASA and Jet Propulsion Laboratory, will determine the positions and distances of stars several hundred times more accurately than any previous program. This accuracy will allow SIM to determine the distances to stars throughout the galaxy and to probe nearby stars for Earth-sized planets. SIM will open a window to a new world of discoveries. Check out the SIM Planet Quest website (*http://planetquest.jpl.nasa.gov/SIM/sim_index.cfm*) for more information on this planned mission.

A list of the projects involved in the search for extrasolar planets is available on the Extrasolar Planet Encyclopedia Web site at http://exoplanet.eu/searches.php.

Things to Think About:

- If a planetary system is listed as having one planet does that mean that we know for certain that only one planet is orbiting the star?

- Many of the planetary systems that have been found so far, with giant planets very close to their stars, look nothing like our own. Does that mean that solar systems like our own are rare?

- How might the discoveries of planets around other stars affect the way scientists view the possibility of finding evidence of life on another planet?

Table 3: A Sampling of Extrasolar Planets

Name of Star	Planet	Year of Planet Discovery	Class of Star	Minimum Mass of Planet	Distance from Star in AU	Scaled Distance from Star
51 Pegasi	b	1995	G	0.47 x M_J	0.05	0.75 m
70 Virginis	b	1996	G	7.4 x M_J	0.48	7.2 m
47 Ursa Majoris	b	1996	G	2.6 x M_J	2.1	31.5 m
	c	2001		1.3 x M_J	7.7	115.5 m
Upsilon Andromedae	b	1996	F	0.69 x M_r	0.06	0.9 m
	c	1999		1.98 x M_J	0.83	12.5 m
	d	1999		3.95 x M_J	2.5	37.5 m
16 Cygni	b	1996	G	1.68 x M_J	1.7	25.5 m
Gliese 876	b	1998	M	1.98 x M_J	0.21	3.15 m
	c	2001		0.56 x M_J	0.13	1.95 m
	d	2005		**0.018 x M_J**	0.02	0.3 m
HD 75289	b	1999	G	0.42 x M_J	0.046	0.69 m
Gliese 581	b	2005	M	0.049 x M_J	0.041	0.62 m
	c	2007		**0.016 x M_J**	0.073	1.1 m
	d	2007		**0.024 x M_J**	0.024	0.36 m
HD 209458	b	1999	G	0.69 x M_J	0.045	0.68 m
HD 82943	b	2000	K	0.4 x M_J	0.04	0.6 m
HD 134987	b	1999	G	1.58 x M_J	0.78	11.7 m
HD 121504	b	2003	G	1.58 x M_J	0.32	4.8 m
Epsilon Eridani	b	2000	K	1.55 x M_J	3.39	50.9 m

M_J is the mass of Jupiter, which is 1,900,000,000,000,000 trillion kg or about 318 times the mass of the Earth. For comparison: Earth's mass is about 0.003 M_J; Neptune's mass is about 0.05 M_J. **Masses in bold indicate probable rocky planets like the Earth.**

An astronomical unit (AU) is 150 million km. Using the same scale factor as for the *Scale Model Solar System* of 1:10 billion, 1 AU = 15 m.

Stars are considered to be object "a" for each planetary system. Planets orbiting them will have the name of the star, and then b, c, d, etc. More information on these and other recently discovered planetary systems is available from the **Extrasolar Planet Encyclopaedia** at http://exoplanet.eu/ and from the **California & Carnegie Planet Search at** http://exoplanets.org/.

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	c	2007		**0.016 x M_J**	0.073	
	d	2007		**0.024 x M_J**	0.024	
HD 209458	b	1999	G	0.69 x M_J	0.045	
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Illustration Credit: NASA/JPL-Caltech/R. Hurt SSC)

In This Exploration:

- *Find out about our galaxy, the Milky Way, and our neighboring galaxies*
- *Create and use a galaxy-sized scale factor to explore distances between galaxies*
- *Classify galaxies and look back in time on a Hubble image*

A Gaggle of Galaxies Teacher Guide

In this exercise, students will model the size of our galaxy, the Milky Way, and the distances between our galaxy and several others in the Local Group of Galaxies. Students will then examine the Hubble Ultra Deep Field, which shows a view of the earliest galaxies in the Universe, and create a classification scheme based on galaxy characteristics. In a discussion of the numerous red galaxies in the Hubble Ultra Deep Field, students will be introduced to the idea of redshift and the Big Bang theory of the origin of the Universe. An expanding balloon or stretchable exercise band will be used to model redshift.

Recommend Prerequisites: Scale Model Solar System, Sizes of Stars

Grade Level: 6-8

Curriculum Standards: A Gaggle of Galaxies 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)

Time Frame: The activity should take approximately 45 minutes to 1 hour to complete, including a short introduction and follow-up.

Purpose: To aid students in understanding the scale of our galaxy and its relationship to other galaxies, how galaxies are classified, and evidence for the Big Bang theory of the origin of the Universe.

Key Concepts:

- Our galaxy, the Milky Way, is a barred spiral containing 200 to 500 billion stars.
- Our own galaxy is one of hundreds of billions of galaxies in the known universe.
- Galaxies are closer together in comparison with their size than are stars.
- Galaxies can take many different forms.
- Galaxies are classified by their morphology.
- The red shift of galaxies in the Hubble Ultra Deep Field is evidence for the Big Bang.

Required Supplies:

- A student sheet for each student
- One color printout of the Hubble Ultra Deep Field for each small group of students
- A light colored balloon or stretchable exercise band for the teacher to use in a demonstration
- A marker (if the balloon is not already marked with a sine wave)

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

Scale Modeling Activities are presented as instructions in the sidebars. The author recommends that students both discuss the information presented in the reading and work through the scale modeling activities in small groups.

Introduction: Before giving students the student reading, ask them what they know about our own galaxy. Some possible questions include:

- What is our galaxy called?
- Why it is called the Milky Way?
- What shape it is the Milky Way?
- How many stars are in the Milky Way?
- How big do they think our galaxy is?
- How many other galaxies are there in the universe?

Our own galaxy, the Milky Way, has between about 200 billion and 500 billion stars. There are so many stars that all but the closest blur together into a milky haze. The Milky Way is a big galaxy, (although not the biggest) at 100,000 light years across (that's 1,000,000,000,000,000,000 km or 1,000,000 trillion km). Our small sun is a star a bit more than halfway out from the center of the galaxy. The Milky Way is a barred spiral galaxy. It has a flat shape with a 3000 light-year-thick bar-like bulge in the middle, and spiral arms. *We live on the edge of the spiral arm called the Orion arm. Almost all of the individual stars you can see when you look up at the night sky are in the same arm of the Milky Way that we are.*

The Galaxies in our Neighborhood

Our galaxy is one of approximately 50 galaxies in a small cluster of galaxies known as the Local Group. Most of the galaxies in the Local Group are small. M 33 (also known as the "Triangulum Galaxy") and M 31 (also known as the "Andromeda Galaxy") are the only other large galaxies in the Local Group, and both are also spiral galaxies. Andromeda is the biggest, at about twice the width of the Milky Way, and M 33 is only 50,000 light years across. Many of the smaller galaxies in the Local Group are satellites of the bigger ones. The Milky Way has several satellite galaxies, including the Large and Small Magellanic Clouds. Distances between star systems are almost unimaginably big compared with the sizes (distances between) of stars, but galaxies can be close together compared with their size.

A Scale Factor Big Enough to Fit Galaxies

Let's imagine we could shrink the Milky Way down to a diameter of 1 m (about the size of a desk) and shrink the rest of the local group by the same amount. We then have a new scale factor, where 1 m on our new scale model equals 100,000 light years in the real local group. The actual Large Magellanic Cloud is 160,000 light years from the center of the Milky Way.

Thinking about the size of the Milky Way

How much space would you need to make a scale model of the Milky Way using a scale factor of 1:10 billion? **Answer**: 100 million km. That's 2/3 of the distance between the Earth and the Sun on our scale model!

If you could build such a model, would it fit on the REAL Earth? **Answer:** No.

Would your model galaxy fit in our REAL

There are about as many galaxies in the known universe as there are stars in the Milky Way. These galaxies come in many different shapes and sizes. With our best telescopes, we can see galaxies more than 13 billion light years away. That means it has taken more than 13 billion years for their light to get to us. The light we see with our telescopes started its journey from the most distant galaxies more than 13 billion years ago. Looking at objects so far away really is looking back in time!

Using Our Galaxy Scale Factor: 1 m = 100,000 ly

If the center of your desk or table is the center of the scale model Milky Way, how far away from the your desk would the scale model Large Magellanic Cloud be? **Answer:** 1.6 m from the center

Andromeda and M33 are the farthest objects in the Local Group. Both are about 3 million light years away from the Milky Way. How far away would the model Andromeda or model M33 be from your desk? **Answer:** 30 m from the center of the desk/table

Would the model Andromeda and M33 fit in your school? Would they fit in your classroom? **Answers:** Probably, No

(Note: on this scale, the distance between the Sun and the Alpha Centauri system would be 0.04 mm, which is too small to see!)

Andromeda Galaxy and M33 Galaxy

Image Credits NASA/JPL/California Institute of Technology, Galaxy Evolution Explorer (GALEX)

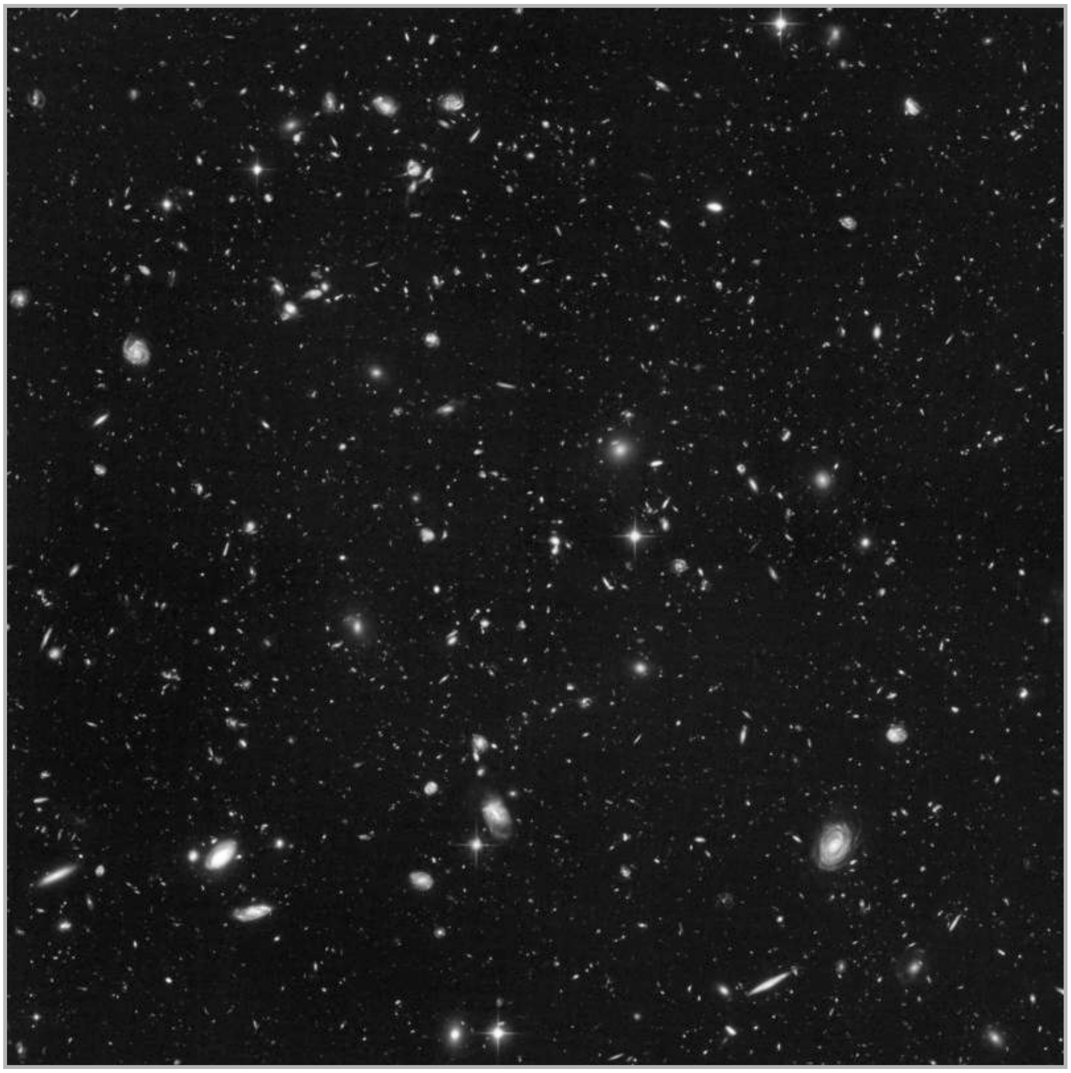

Image Credit: NASA, ESA, S. Beckwith (STScI) and the Hubble Ultra Deep Field Team

Using the Hubble Ultra Deep Field: Break your students into groups of two - three students and give each group a color copy of the Hubble Ultra Deep Field. Have them read the information sheet individually in groups, or as a class.

This Hubble Ultra Deep Field image is a picture of 10,000 extremely distant galaxies in a very tiny area of the sky. (This image is of an area of the sky the tenth of the size of the full moon as seen from Earth.) The Hubble Space Telescope took this composite image in 2004 using two different cameras. One camera used infrared light to see the small, most distant, and reddest galaxies in the image. Some of the galaxies that look the biggest and the brightest are a bit closer, but still about 13 billion light years away. One thing you should be able to see in the picture is that galaxies come in many different shapes. (A few stars in our own galaxy are also in this image, but you can tell those by the four points of light that they seem to have because they are so bright compared to the distant galaxies.)

Galaxy Activity

Look carefully at the Hubble Ultra Deep Field.

- *Can you find galaxies that look similar to one another?*

Now come up with a classification scheme of your own.

- *Pick a name for a type of galaxy, and list three characteristics of that galaxy.*
- *Do this for three different types of galaxies.*

Name of Galaxy Type	***Characteristics***
Example: Spiral	*Flat, pancake shaped, spiral arms.*

How Astronomers Classify Galaxies.

Astronomers classify galaxies by their shapes into three major categories: elliptical, spiral (normal and barred), and irregular. Your students may come up with some much more creative names and descriptions! What is important is that they use their observations to categorize galaxies. Be sure they understand the task is not to name individual galaxies.

Redshift and the electromagnetic spectrum:

Before discussing the concept of redshift, your students may need an introduction or review of the electromagnetic spectrum, including wavelength and color.

Red Galaxies, Expansion of the Universe, and the Big Bang

The small red galaxies in the Hubble Deep Field are the farthest away from us. The fact that they are so red is also evidence for the Big Bang!

Not so long ago, astronomers thought that the Milky Way was the entire universe, and that the universe remained static (unchanging) with time. Astronomers didn't even realize that there were other galaxies until the 1920s. Edwin Hubble *realized that many "nebula" which astronomers had found were distant galaxies. He also discovered something else very strange – the farther away the galaxies were, the more red their light had become. This* ***red shift*** *showed that most galaxies were moving away from each other, which led to the idea of the* ***Big Bang****. If galaxies are moving apart, at some point in the past, they must have been close together.*

The universe had a beginning, which we now call the Big Bang. The idea that the universe began billions of years ago and has been expanding ever since was very strange to scientists when it was first suggested. Even Albert Einstein had accepted the idea of a static universe before Hubble's observations. The reddest galaxies in the Hubble Ultra Deep Field look so red that a special infrared camera had to be used to see them. The universe is about 14 billion years old, and the light we see was emitted only 800 million years after the universe was born.

Space Expansion Demo: Take a light colored balloon or stretchable and draw a wave on it with several equally spaced peaks and valleys. Ask the students to watch carefully as you inflate the balloon, or stretch the exercise band.

Imagine a balloon that has a picture of a wave drawn on it.

This wave represents a wave of light.

Now inflate the balloon. What happens?

The peaks and valleys of the wave stretch out and become farther apart. The ***wavelength*** *has increased. If the wave was visible light, the light would be more red because red light has the longest wavelength of all visible light. The balloon represents the expansion of space that has continued since the Big Bang. Early in the Universe, the galaxies were much closer together. The light emitted by far away galaxies has been expanding with the Universe since the moment it was emitted.*

Note: When using a balloon for this demonstration, the students may think that the amplitude (height) of the wave increases too. It doesn't. That is a limitation of using a balloon for this demonstration. A material that stretches in only one dimension will not have problem.

Do the galaxies, stars, planets, and people expand with the Universe? No. We are held together by gravity or by the materials we are made of. Galaxies that aren't kept together by gravity are pulled apart from one another, but their stars and planets travel with them. Each galaxy is like a little island universe in space. Think of galaxies as raisins in a loaf of bread dough rising in the oven. As the bread expands, the raisins get further apart.

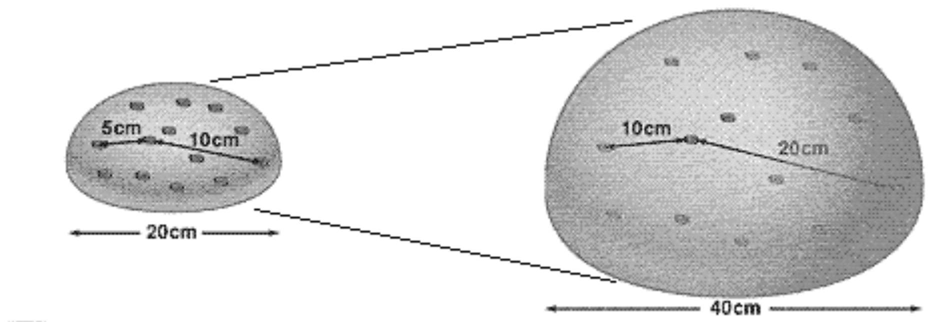

Image adapted from http://map.gsfc.nasa.gov/m_uni/uni_101bbtest1.html

Using glitter or other non-expanding objects on the surface of the balloon or stretchable band will help illustrate this concept for the students.

Internet Extension:

Have students compare and contrast galaxies and clusters of galaxies as seen by the Hubble Space Telescope, Spitzer Space Telescope, and from ground-based telescopes as seen in the SEDS Messier Database or the Astronomy Picture of the Day. Many of the galaxies have strange names such as M 33 or NGC 1300, which are really just astronomical catalog designations. What similarities and differences can your students find in galaxies in these images?

From Hubble Space Telescope (hubblesite.org)

- Coma Galaxy Cluster: http://hubblesite.org/newscenter/newsdesk/archive/releases/1995/07/
- Hickson Compact Group 87 http://hubblesite.org/newscenter/newsdesk/archive/releases/1999/31/
- Barred Spiral http://hubblesite.org/newscenter/newsdesk/archive/releases/2005/01/
- Spiral http://hubblesite.org/newscenter/newsdesk/archive/releases/2004/25/
- Ring Galaxy (once an ordinary spiral) http://hubblesite.org/newscenter/newsdesk/archive/releases/2004/15/
- Spiral with aging (bright red) star http://hubblesite.org/newscenter/newsdesk/archive/releases/2004/43/

- Sombrero Galaxy
  http://hubblesite.org/newscenter/newsdesk/archive/releases/2003/28/
- Colliding Spirals
  http://hubblesite.org/newscenter/newsdesk/archive/releases/1999/41/
- Small Elliptical Galaxy
  http://hubblesite.org/newscenter/newsdesk/archive/releases/1999/40/

From SEDS Messier Database (http://www.seds.org/messier/)

- Andromeda Galaxy (M 31) in the Local Group
  http://www.seds.org/messier/xtra/ngc/lmc.html
- Trianglulum Galaxy (M 33) in the Local Group
  http://www.seds.org/messier/m/m033.html
- Large Magellanic Cloud (satellite galaxy of the Milky Way)
  http://www.seds.org/messier/xtra/ngc/lmc.html
- Small Magellanic Cloud (satellite galaxy of the Milky Way)
  http://www.seds.org/messier/xtra/ngc/smc.html
- Giant Elliptical M87 at the heart of the Virgo Cluster
  http://www.seds.org/messier/m/m087.html

Illustration Credit: NASA/JPL-Caltech/R. Hurt SSC)

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- Find out about our galaxy, the Milky Way, and our neighboring galaxies
- Create and use a galaxy-sized scale factor to explore distances between galaxies
- Classify galaxies and look back in time on a Hubble image

A Gaggle of Galaxies

Our own galaxy, the Milky Way, has between about 200 billion and 500 billion stars. There are so many stars that all but the closest blur together into a milky haze. The Milky Way is a big galaxy, (although not the biggest) at 100,000 light years across (that's 1,000,000,000,000,000,000 km or 1,000,000 trillion km). Our small sun is a star a bit more than halfway out from the center of the galaxy. The Milky Way is a barred spiral galaxy. It has a flat shape with a 3000 light-year-thick bar-like bulge in the middle, and spiral arms. We live on the edge of the spiral arm called the Orion arm. Almost all of the individual stars you can see when you look up at the night sky are in the same arm of the Milky Way that we are.

Thinking about the size of the Milky Way

How much space would you need to make a scale model of the Milky Way using a scale factor of 1:10 billion?

If you could build such a model, would it fit on the REAL Earth?

Would your model galaxy fit in our REAL solar system?

The Galaxies in our Neighborhood

Our galaxy is one of approximately 50 galaxies in a small cluster of galaxies known as the Local Group. Most of the galaxies in the Local Group are small. M 33 (also known as the "Triangulum Galaxy") and M 31 (also known as the "Andromeda Galaxy") are the only other large galaxies in the Local Group, and both are also spiral galaxies. Andromeda is the biggest, at about twice the width of the Milky Way, and M 33 is only 50,000 light years across. Many of the smaller galaxies in the Local Group are satellites of the bigger ones. The Milky Way has several satellite galaxies, including the

Large and Small Magellanic Clouds. Distances between star systems are almost unimaginably big compared with the sizes (distances between) of stars, but galaxies can be close together compared with their size.

A Scale Factor Big Enough to Fit Galaxies

Let's imagine we could shrink the Milky Way down to a diameter of 1 m (about the size of a desk) and shrink the rest of the local group by the same amount. We then have a new scale factor, where 1 m on our new scale model equals 100,000 light years in the real local group. The actual Large Magellanic Cloud is 160,000 light years from the center of the Milky Way.

There are about as many galaxies in the known universe as there are stars in the Milky Way. These galaxies come in many different shapes and sizes. With our best telescopes, we can see galaxies more than 13 billion light years away. That means it has taken more than 13 billion years for their light to get to us. The light we see with our telescopes started its journey from the most distant galaxies more than 13 billion years ago. Looking at objects so far away really is looking back in time!

Andromeda Galaxy and M33 Galaxy

Image Credits NASA/JPL/California Institute of Technology, Galaxy Evolution Explorer (GALEX)

Using Our Galaxy Scale Factor:

1m = 100,000 ly

If the center of your desk or table is the center of the scale model Milky Way, how far away from the your desk would the scale model Large Magellanic Cloud be?

Andromeda and M33 are the farthest objects in the Local Group. Both are about 3 million light years away from the Milky Way. How far away would the model Andromeda or model M33 be from your desk?

Would Andromeda and M33 fit in your school? Would they fit in your classroom?

(Note: on this scale, the distance between the Sun and the Alpha Centauri system would be 0.04 mm, which is too small to see!)

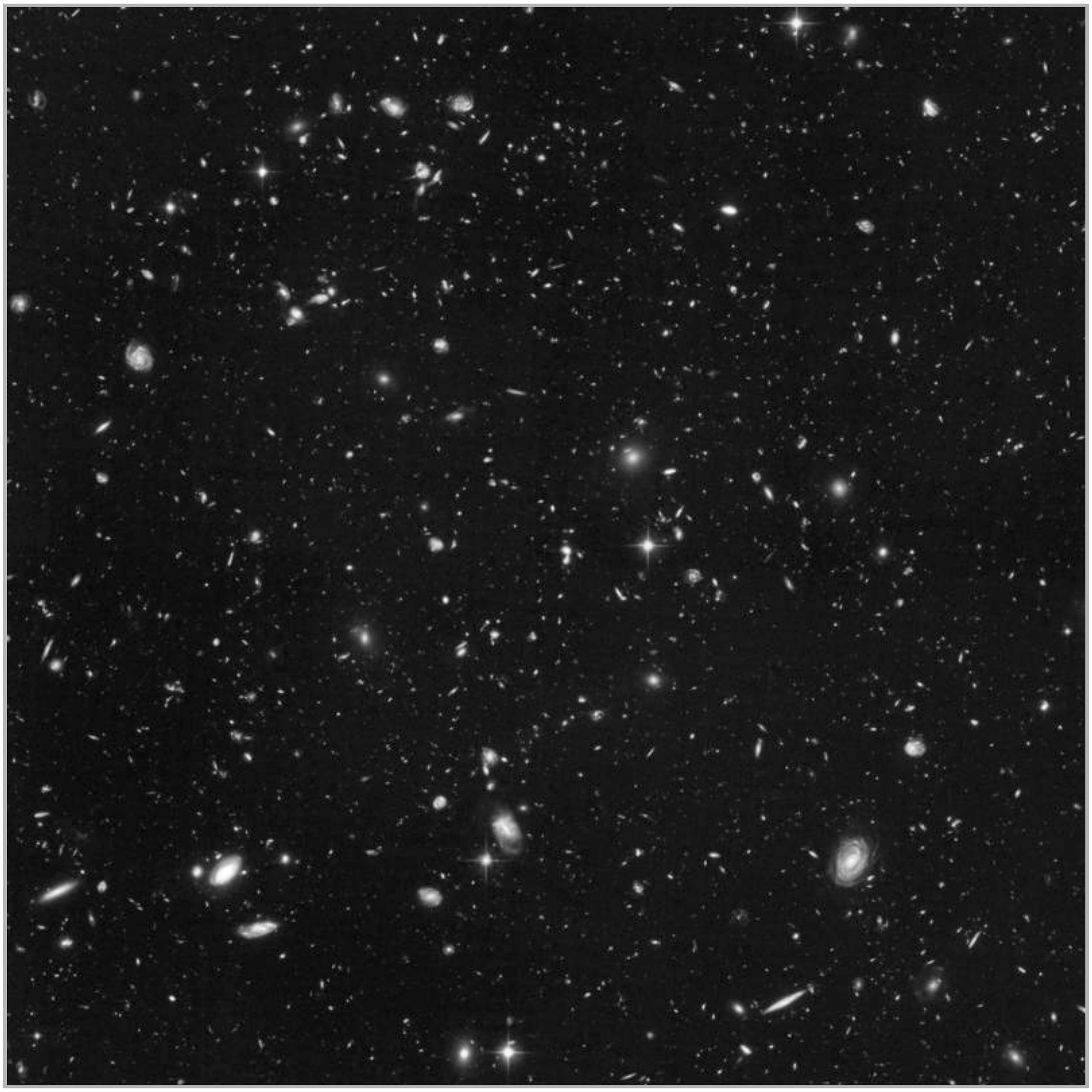


Image Credit: NASA, ESA, S. Beckwith (STScI) and the Hubble Ultra Deep Field Team

This Hubble Ultra Deep Field image is a picture of 10,000 extremely distant galaxies in a very tiny area of the sky. (This image is of an area of the sky the tenth of the size of the full moon as seen from Earth.) The Hubble Space Telescope took this composite image in 2004 using two different cameras. One camera used infrared light to see the small, most distant, and reddest galaxies in the image. Some of the galaxies that look the biggest and the brightest are a bit closer, but still about 13 billion light years away. One thing you should be able to see in the picture is that galaxies come in many different shapes. *(A few stars in our own galaxy are also in this image, but you can tell those by the four points of light that they seem to have because they are so bright compared to the distant galaxies.)*

Galaxy Activity

Look carefully at the Hubble Ultra Deep Field.

- Can you find galaxies that look similar to one another?

Now come up with a classification scheme of your own.

- Pick a name for a type of galaxy, and list three characteristics of that galaxy.
- Do this for three different types of galaxies.

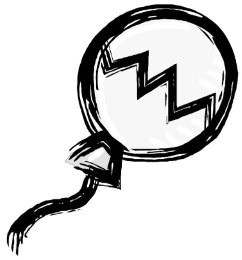
Name of Galaxy Type	Characteristics
Example: Spiral	Flat, pancake shaped, spiral arms.

Red Galaxies, Expansion of the Universe, and the Big Bang

The small red galaxies in the Hubble Deep Field are the farthest away from us. The fact that they are so red is also evidence for the Big Bang!

Not so long ago, astronomers thought that the Milky Way was the entire universe, and that the universe remained static (unchanging) with time. Astronomers didn't even realize that there were other galaxies until the 1920s. Edwin Hubble realized that many "nebula" which astronomers had found were distant galaxies. He also discovered something else very strange – the farther away the galaxies were, the more red their light had become. This **red shift** showed that most galaxies were moving away from each other, which led to the idea of the **Big Bang**. If galaxies are moving apart, at some point in the past, they must have been close together.

The universe had a beginning, which we now call the Big Bang. The idea that the universe began billions of years ago and has been expanding ever since was very strange to scientists when it was first suggested. Even Albert Einstein had accepted the idea of a static universe before Hubble's observations. The reddest galaxies in the Hubble Ultra Deep Field look so red that a special infrared camera had to be used to see them. The universe is about 14 billion years old, and the light we see was emitted only 800 million years after the universe was born.



Imagine a balloon that has a picture of a wave drawn on it.

This wave represents a wave of light. 

Now inflate the balloon. What happens?

The peaks and valleys of the wave stretch out and become farther apart. The **wavelength** has increased. If the wave was visible light, the light would be more red because red light has the longest wavelength of all visible light. The balloon represents the expansion of space that has continued since the Big Bang. Early in the Universe, the galaxies were much closer together. The light emitted by far away galaxies has been expanding with the Universe since the moment it was emitted.

Do the galaxies, stars, planets, and people expand with the Universe? No. We are held together by gravity or by the materials we are made of. Galaxies that aren't kept together by gravity are pulled apart from one another, but their stars and planets travel with them. Each galaxy is like a little island universe in space. Think of galaxies as raisins in a loaf of bread dough rising in the oven. As the bread expands, the raisins get further apart.

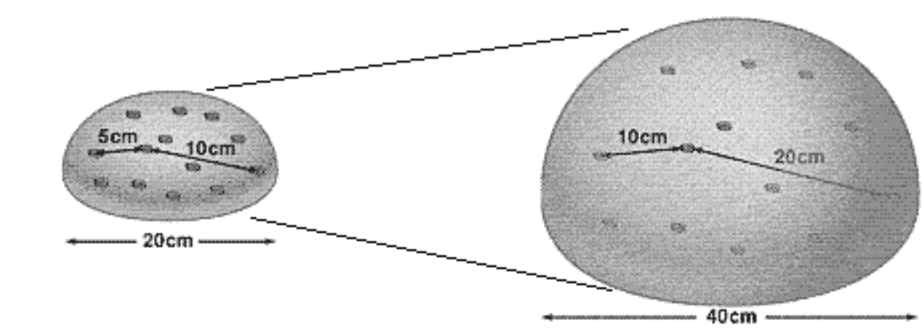


Image adapted from http://map.gsfc.nasa.gov/m_uni/uni_101bbtest1.html