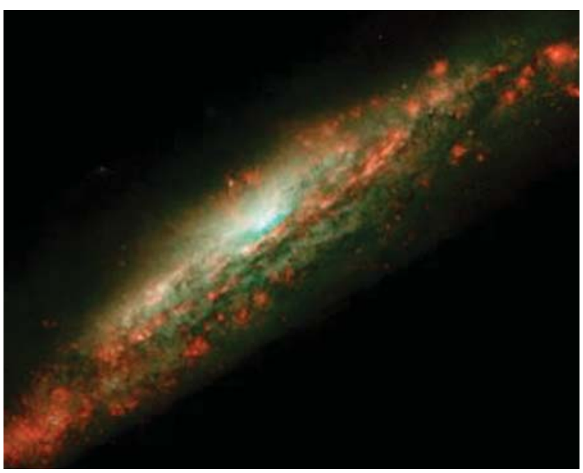
THE LIFE CYCLE OF STARS

Background Information

Galaxies

Stars are massive collections of atomic particles that create light and heat at their centers. The first atoms formed from the hot gas of subatomic particles created when the universe began. Then gravity forced the atoms to join together into ever larger clusters. Those clusters grew large enough that their gravity attracted other groups of atoms, until stars eventually formed. Those stars attracted other stars until small galaxies formed. Those galaxies attracted other galaxies, finally forming large, mature galaxies such as the Milky Way.

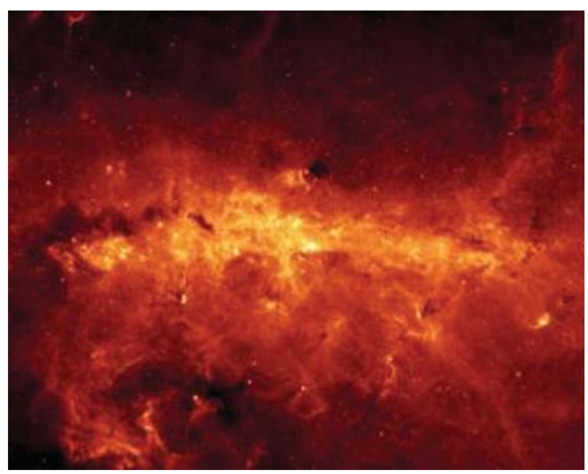


A distant galaxy

Galaxies continue to influence each other. Although the Milky Way as a whole is stable, small changes continue — stars continue to be born, while others either die quietly or explode as supernovas. Dying stars contribute gas and dust to the already vast amount that clogs the Milky Way. Because the Milky Way forms a **plane**, a flat, two-dimensional, plate-like shape, the dust makes it difficult to see across the Milky Way.

Did you know?

- The Milky Way galaxy contains approximately 400 billion stars.
- There are several hundred billion galaxies in the universe.
- Each year, the Milky Way creates about seven new stars.
- A supernova occurs about once every 50 years in the Milky Way galaxy. Many supernovas occur that are not visible from the earth, but since the last one observed from earth occurred in 1604, the next visible supernova is overdue.



Gas and dust clog the heart of the Milky Way

A star's life

Supernova explosions or changes in the rotation of the Milky Way can cause a **nebula**, a massive cloud of gas and dust in outer space, to contract. As the nebula contracts under its own gravity, gas and dust accumulate into ever larger bodies. The result is often the formation of **protostars**, dense bodies of gas and dust that have not yet begun to generate light. As the mass of each protostar increases, its gravity also increases, which squeezes the core of the protostar ever harder.

Finger-like protrusions hold new stars in nebula

When the hydrogen atoms at the core of a protostar are squeezed at high enough temperatures and pressures, they fuse together to create new helium atoms. This is called **stellar nucleosynthesis**, the process in which four hydrogen atoms combine together to produce a single helium atom at the center of a star. This interesting term has three parts:

- **Stellar** means star.
- Nucleo is short for nucleus or **nuclear**, having to do with the nucleus at the center of an atom.
- Synthesis refers to the process of combining.

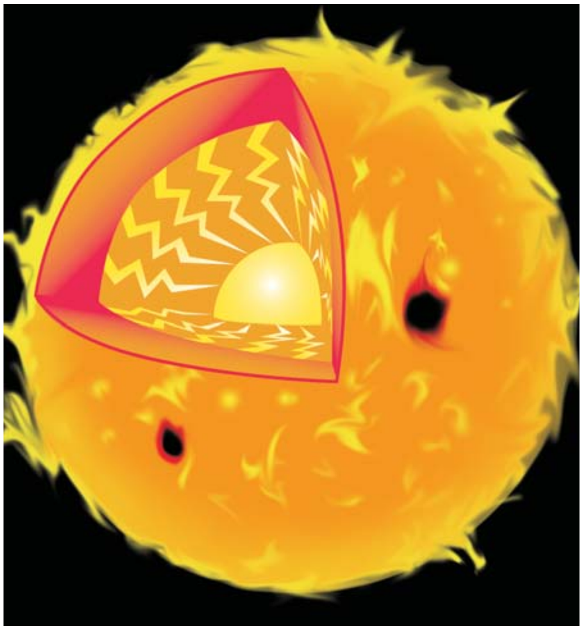
The new helium atom, however, has 0.7 percent less mass than the total mass of the four hydrogen atoms from which it was created. Most of that tiny bit of mass is converted into **nuclear energy**, the fundamental material from which mass of the universe is formed. Nuclear energy was predicted by Albert Einstein's famous equation, $E=MC^2$, which means: "energy equals mass times the speed of light squared." That little bit of mass is the fuel that the protostar burns, turning it into light and heat in the form of **photons**, particles of light energy. When nucleosynthesis begins in a protostar, it becomes a star, and photons leave the star as light and heat.

The sun was created by this process. The sun is a **yellow dwarf star**, a common type of star of average dimensions and mass. About a million years after its formation, the sun, like all yellow dwarf stars, entered the **main sequence**, the main portion of the life cycle of an average star, in which it converts hydrogen into helium steadily for billions of years. It takes an average star like the sun 10 billion years to convert the hydrogen in its core to helium. The sun is currently middle-aged, about 5 billion years old.

The light and heat radiating outward from the core of the sun and the steady gravitational pressure of the outer layers upon the core are in balance in the sun — the outward pressure equals the inward pressure. At the end of its 10 billion years as a main sequence star, however, when the hydrogen in the core has all been turned to helium, the amount of energy released decreases.

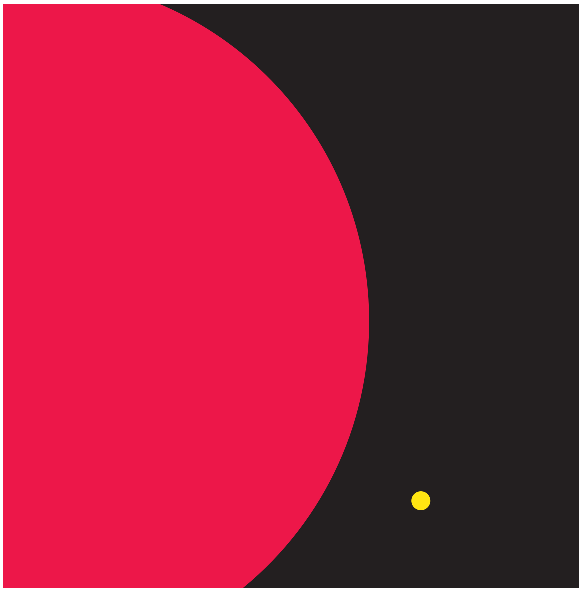
Did you know?

- The sun turns 700 million tons (635 metric tons) of hydrogen into helium every second through stellar nucleosynthesis. Of that 700 million tons (635 metric tons), 0.7 percent, or 5 million tons (4.5 metric tons), of hydrogen is converted into pure energy and released as photons every second.
- The internal temperature of the sun is 28 million degrees F (16 million degrees C).
- The sun is 432,000 mi (696,000 km) across. If the sun were to become a black hole, the entire mass of the sun would be squeezed until it was only 2 mi (3 km) across.



The interior the sun – an average star

In the absence of the steady outward pressure of light and heat, the outer layers will press in on the core, increasing the



A red giant star and the sun

temperature and pressure until the layer of hydrogen around the helium core begins to burn. The light and heat from that layer of hydrogen will inflate the sun hundreds of times its original size, making it shine up to 2,000 times brighter. At this point, the sun will become a **red giant**, a greatly expanded star whose outer layer is so distant from the burning hydrogen layer that the surface is relatively cool. Its red color shows that it is relatively cool in the same way that red-hot metal is cooler than white-hot metal.

A planetary nebula with a white dwarf star in its center.

The sun will contract and expand several times until its outer layers detach from the remaining core, creating a **planetary nebula**, a shell of glowing gas around a shrunken, dying star. (The earliest astronomers thought these objects were planets, hence the name.) The remaining star is called a **white dwarf**, an old star about the size of the earth that will radiate the light and heat trapped within it for millions of years, before cooling and darkening into a **black dwarf**, a cold, dead remnant of a star.

Death and birth of stars

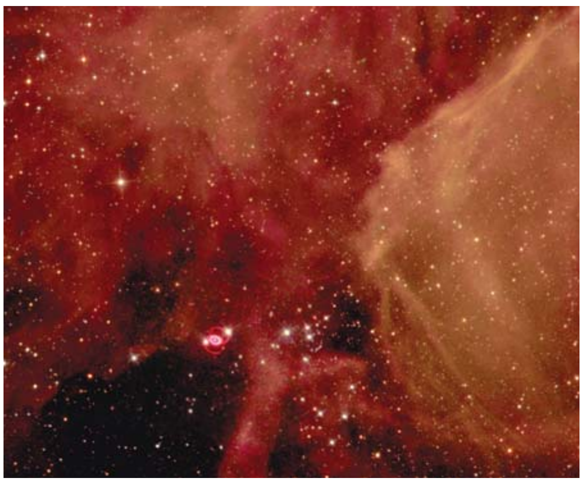
Not all stars fall within the main sequence, however. Many are either too small or too large to maintain stellar nucleosynthesis. It is often the case that there is not enough gas and dust available to form a star big enough to support nucleosynthesis. The result is a **brown dwarf**, an object in outer space that is large enough to generate heat from gravitational pressure, but not large enough to generate light through stellar nucleosynthesis. It is estimated that brown dwarfs are as common as main sequence stars and are often companions to them, like very large, hot planets.

The smallest object that can properly be called a star is a **red dwarf**, a star with approximately 8–80 percent of the mass of the sun. A red dwarf follows the same life cycle as a main sequence star like the sun, but remains smaller and cooler throughout its life, with surface temperatures about half that of the sun. It is estimated there are as many red dwarfs as there are other types of stars.

Stars that are too large to enter the main sequence are known as **giant stars**, stars whose masses are more than six times that of the sun. The great mass of a giant star creates tremendous gravity and thus great heat and pressure in its core, causing the star to convert all of its hydrogen to helium in a few million years. When its hydrogen is exhausted, the giant star expands and contracts like a main sequence star. It goes through a phase as a **supergiant star**, a hugely expanded star that can be over 1,000 times larger than the sun, with a light output 600,000 times greater.

Giant, yellow dwarf, and supergiant stars

When the hydrogen in the core of a supergiant star is exhausted, the radiation of light and heat from the core can no longer support the outer layers. The outer layers collapse in upon the core suddenly and then rebound in a supernova explosion. The explosion sends the outer layers flying off into space at tremendous speed, releasing as much energy in seconds as the sun will release in its lifetime, while the remaining core is crushed down into an incredibly small remnant.



Supernova 1987A

If the original giant star was six to ten times the mass of the sun, the core collapses to form a **neutron star**, an extremely dense star approximately 12 mi (20 km) in diameter. If the original star was more than ten times the mass of the sun, the core collapses to form a **black hole**, an object approximately 6–12 mi (10–20 km) in diameter whose gravity is so powerful that even light cannot escape.

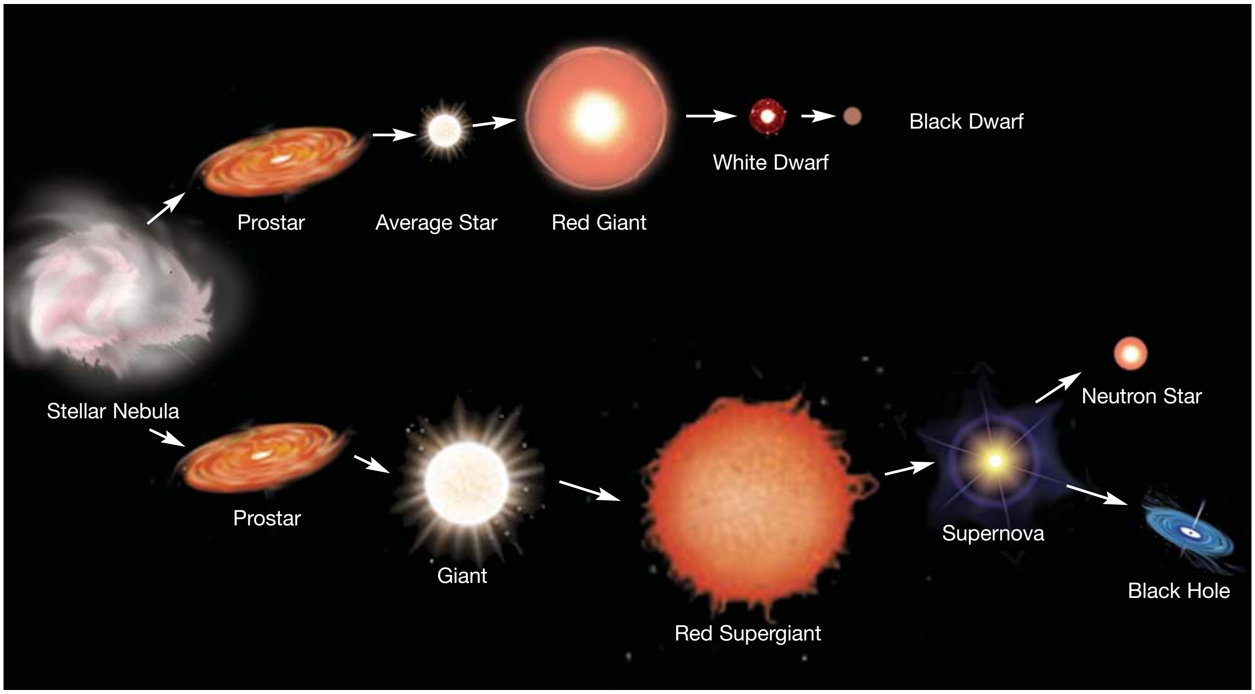
In sum, stars come in many sizes and colors, from tiny red dwarfs that barely qualify as stars, to massive supergiants so big and bright that they would make the sun look like a very dim light bulb if put side by side. Despite how far away they are, the variations in stars are often visible from earth. Astronomers attribute those variations to each star's size, the amount of light radiated, its distance from the earth, and its color.

The simplest measure of a star's brightness is its **luminosity**, a measure of the amount of light energy produced by a star. Temperature and size have the most effect on the luminosity of a star, and temperature also determines the color. The bigger a star is, the greater the temperature and pressure in the core, the more nucleosynthesis occurs, the more light it will give off, and the more blue-white it will be. The smaller and cooler a star is, the less light it will give off, and the more red it will be.

Astronomers also compare the brightness of stars against each other in two different ways:

- **Absolute magnitude** compares the brightness of stars as if viewed from the same distance, so that a star's absolute magnitude is determined by its size and temperature, not by how close it is to the earth.
- **Apparent magnitude** compares the brightness of stars when viewed from the earth, so that a star's apparent magnitude is determined by its absolute magnitude or luminosity, its distance from earth, and any obscuring **interstellar material**, gas and dust between stars and the earth.

Many different factors thus make a star appear more or less bright when seen from the earth. If two stars are an equal distance from the earth, the larger star will appear



Possible life cycles of a star

brighter. However, if the smaller star is a young, hot star shining with a brilliant blue-white light (that is, with greater luminosity), it may appear brighter here on earth than a larger but cooler red giant. And a supergiant will outshine all other stars at an equal distance because of both its size and luminosity.

Orion constellation

An example of how absolute magnitude and distance combine to affect a star's apparent magnitude occurs in the Orion **constellation**, the named pattern of stars in the night sky. The three stars in a row that form Orion's "belt" are all of approximately the same apparent magnitude as seen from earth. In fact, the center star of the three is twice as far away from the earth as the other two stars, but it is so much bigger and hotter that it appears just as bright.

Resources

There are many excellent books, websites, and videos about stars. Here are some examples:

Campbell, Janis, and Cathy Collision. *G is for Galaxy: An Out of this World Alphabet.* Chelsea, MI: Sleeping Bear Press, 2005.

Frantz, Jennifer. *Looking at the Night Sky.* New York, NY: Grosset & Dunlap, 2002.

Hollands, Simone. *Eye Wonder: Space.* London, UK: Dorling Kindersley Ltd., 2001.

Petty, Kate. *I Didn't Know: Sun is a Star.* Allston, MA: Fitzhenry & Whiteside, 2004.

Sims, Nikki, ed. *Stargazer.* New York, NY: Dorling Kindersley Ltd., 2004.

<http://amazing-space.stsci.edu/resources/explorations/>

<http://spaceplace.nasa.gov/en/kids/>

<http://starchild.gsfc.nasa.gov/docs/StarChild/universe_level1/universe.html>

NOVA. *Death of a Star.* NOVA, producer. Boston, MA: WGBH Educational Foundation, 1987. # 1-884738-22-2. 60 min. Videocassette.

Did you know?

- The brightest star in the sky, Sirius A, also known as the "Dog Star," is actually a pair of stars. Sirius A has a tiny companion, a white dwarf named Sirius B. It is believed that the majority of stars may exist in pairs, triplets, and even quadruplets and quintuplets. In fact, single stars such as the sun may be the exception.

- A neutron star is tiny — about the size of a large city. A teaspoon of that star would weigh as much as several office buildings

ACTIVITY 1

Making a Model Showing the Formation of a Protostar

Purpose

To understand how an average protostar forms.

Material

2 cups (500 mL) white, yellow, or red modeling or sculpting clay.

At least 40 marble-size balls of modeling or sculpting clay prepared ahead of time, so there is a total of at least 50 balls after the students make four each from the required 2 cups (500 mL).

Illustration: Gas and dust clog the heart of the Milky Way.

Illustration: Finger-like protrusions hold new stars in nebula.

Matter and Astronomy Journal and pencils.

Presentation

- Most Montessori teachers introduce this concept in Year 2 or 3.
- Announce to the students that they will be making a model showing how an average protostar forms.

INTRODUCTION

- Review the concept of atoms (everything is made up of atoms; following the formation of the universe, hydrogen atoms, the simplest and most plentiful atoms, were the first thing to form; those atoms joined together to make protostars).
- Explain that the hydrogen gas from which protostars form is plentiful in the Milky Way galaxy. Present the illustration, Gas and dust clog the heart of the Milky Way, explaining that all the dark areas are hydrogen gas and dust from dead stars that are formed from protostars.

MODEL OF A PROTOSTAR

- Present the modeling or sculpting clay and explain that the students will use it to make pretend atoms of hydrogen. Make a marble-size ball so that the students know how large to make their own, then distribute the rest of the clay and invite the students to make four marble-size balls each.
- Ask the students to put their hydrogen atoms into a clearing at the center of the table, spread out loosely so none are touching. Add any extras that were pre-

made. Explain that following the formation of the universe, hydrogen atoms were all spread out like the marbles of clay.

- Discuss with the students what gravity does to things (pulls them toward each other and makes them stick together). Point out that gravity made the hydrogen atoms stick together. With the students, start sticking the model atoms together, but not so that they lose their shape and individual identities.
- Ask the students to continue to create an ever larger collection of atoms until all the model atoms are used up. Gently shape the final product into a ball made up of individual smaller balls. Explain that in the universe, once all the free atoms were absorbed into a single ball like this, a protostar was created.
- Present the illustration, Finger-like protrusions hold new stars in nebula. Explain that it shows a protostar forming in a cloud of gas and dust.
- Keep the ball model for use in Activity 2, Exploring How a Protostar Becomes a Star.
- Ask the students to use their journals to draw and label an illustration showing how atoms combine to create a protostar.

Extensions

- With each student playing the part of a hydrogen atom, act out the role of gravity in the creation of a protostar.

ACTIVITY 2

Exploring How a Protostar Becomes a Star

Purpose

To understand how a star is formed and begins to make light and heat.

Material

Model made in Activity 1: Making a Model Showing the Formation of a Protostar.

Ball of modeling or sculpting clay of a different color than that used in Activity 1, approximately the same size as four of the smaller balls from which the model protostar is formed.

Illustration: The interior of the sun — an average star.

Whiteboard and marker.

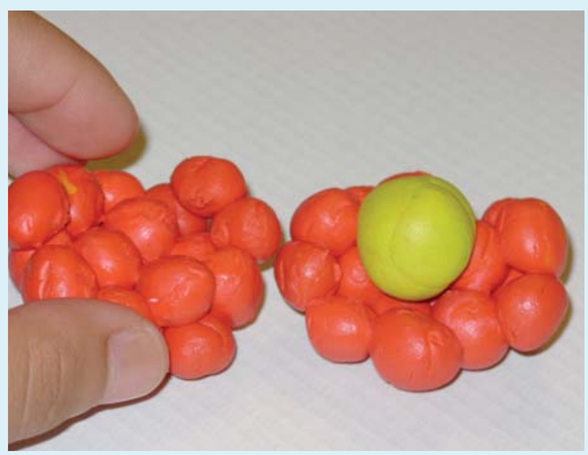
Matter and Astronomy Journal and pencils.

Presentation

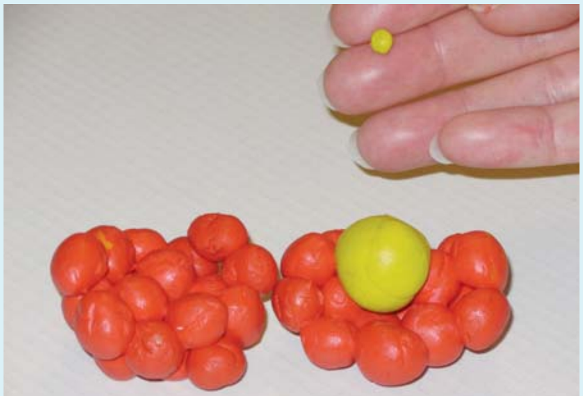
- Most Montessori teachers introduce this concept in Year 1 or 2.
- Announce to the students that they will be studying how a protostar becomes a star showing light.

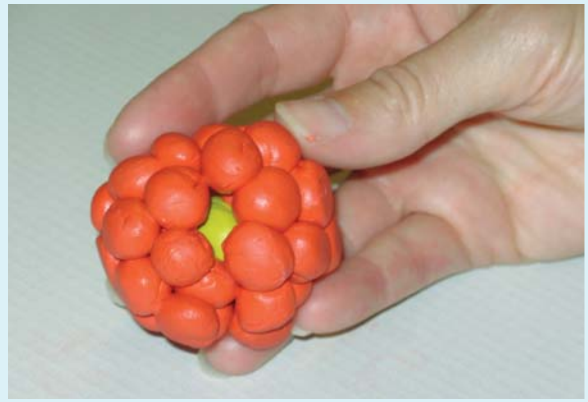
PROTOSTAR MODEL

- Demonstrate the protostar made in the previous activity. Briefly review with the students that the modeling dough ball represents a protostar made up of hydrogen atoms held together by gravity. Explain that the atoms in the center of the protostar get squeezed by gravity the most because they have the most atoms piled on top of them, and that this causes them to change.
- Gently pry the ball apart into two roughly equal halves, so the inner core is exposed. Explain that the atoms in the core get squeezed so much that groups of four hydrogen atoms join together to form one large, heavy helium atom.
- Take four balls from the very center of the model and squeeze them together into a single ball. Then ask a student to make a ball of the same size, but using the different color of modeling dough.
- Invite another student to place the new ball (the one of a different color) in the center of the protostar. Point out that the atoms at the center of the protostar are now helium atoms instead of hydrogen.



- Explain that when the helium atom forms, a tiny bit of hydrogen gets left over. Pinch off about 1/100 of the helium atom ball in the center of the protostar.





STELLAR NUCLEOSYNTHESIS

- Explain that the tiny bit of leftover hydrogen atom is the fuel that the protostar burns and turns into light and heat in the form of photons. Point out that when this process begins in a protostar, it becomes a star, and photons leave the star as light and heat. Point out that the sun is an example of a star and that light and heat eventually leave the sun and shine on the earth.

- Present the illustration, The interior of the sun — an average star. Invite the students to find the core and the other layers.

- Explain that this process of hydrogen atoms joining to form helium atoms is called stellar nucleosynthesis. On the whiteboard, write the term and the three words that make it up. Invite the students to say the words aloud.

- Gently replace the ball representing the helium atom in the center of the model, this time referring to the model as a star, no longer a protostar. Put the ball back together carefully, and retain it for Activity 3, Exploring the Life Cycle of an Average Star.

- Ask the students to use their journals to draw and label an illustration showing how a protostar becomes a star.

Extensions

- Write a short explanation about what the term "stellar nucleosynthesis" means.

- Find a book about Albert Einstein and write a paragraph about why he is well known. Include his famous formula.

- Research nuclear energy, then write a paragraph defining it and listing one advantage and one disadvantage.

ACTIVITY 3

Exploring the Life Cycle of an Average Star

Purpose

To understand how an average star like the sun ends its life.

Material

Model from Activity 2: Exploring How a Protostar Becomes a Star.

One white marble, or small white ball of modeling dough.

Illustration: A red giant star and the sun.

Illustration: A planetary nebula with a white dwarf star in its center.

Illustration: Possible life cycles of a star.

Matter and Astronomy Journal and pencils.

Presentation

- Most Montessori teachers introduce this concept in Year 2 or 3.

- Before the presentation, gently pry open the model from Activity 2 and embed the white marble in the center.

- Announce to the students that they will be studying the life cycle of an average star such as the sun.

REVIEW

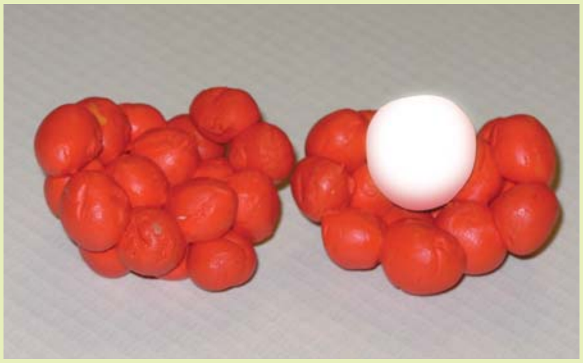
- With the students, review how stars form. Emphasize that a star shines by converting hydrogen to helium.

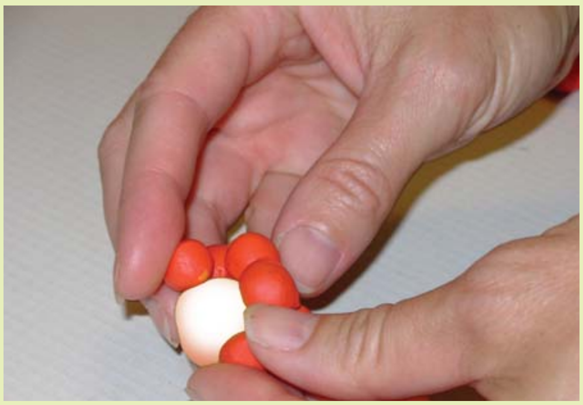
- Review that the sun formed this way and that it is an average star. Explain that the sun formed 5 billion years ago and that it will continue to burn its hydrogen fuel for another 5 billion years. Relate that all of history, from before the formation of the earth to today, has taken place in the first 5 billion years, and that there is still another 5 billion years left. Add that the sun is called a yellow dwarf star because it is yellow in color and relatively small.

RED GIANT

- Present the model containing the white marble. Explain that the students will use the star to show what happens when a star runs out of hydrogen in its core.

- Gently break open the model to show the white marble in the center. Explain that the marble represents a single solid helium atom and that a billion years from now, all of the hydrogen in the core will be turned to helium. Then the outer layers will start to squeeze tighter, until the hydrogen around the core starts to burn.





- If possible, take some of the modeling dough atoms from the inside of the outer shell of the model and stick them to the helium core, spreading them over the surface of the core.

- Explain that when the hydrogen atoms around the helium core start to turn into helium, they release light and heat, which inflates the outer layers like a balloon until the star is up to a thousand times bigger than it is, which would mean that the modeling dough star would fill the room. Use your arms to mimic the expansion of the star filling the room.

- Explain that because the outer layers are so far from the hot layer of hydrogen around the core, the outer layers are much cooler than they used to be, so that they are more red than white, just like a red-hot element on an electric stove is cooler than the white element in a light bulb. Hence the star is then called a red giant. Present the illustration, A red giant star and the sun.

WHITE DWARF TO BLACK DWARF

- Explain that when there is no more hydrogen around the core to convert to helium, the core contracts to form a white dwarf, a small white star that is no longer generating its own light and heat, but only shines because of leftover light and heat. The outer layers of the star break away from the white dwarf, flying off in all directions, where they become material for new stars.

- Remove the white marble from inside the helium core. Invite the students to imagine all the rest of the star is flying off into outer space.

- Present the illustration, A planetary nebula with a white dwarf in its center. Point out the white dwarf at the center and explain that the colored layers are the outer layers of the star flying off into space. Explain that the white dwarf will slowly cool over millions of years, turning red, then brown, and finally black, just like a fire going out.

SUMMARY

- Present the illustration, Possible life cycles of a star. With the students trace the life cycle of an average star.

- Ask the students to use their journals to draw and label an illustration showing the major stages in the life cycle of an average star.

Extensions

- Write a sentence or two explaining the difference between red giant, yellow dwarf, and white dwarf stars.
- Research the sun and write three interesting new facts about it.
- Contact a local astronomy club and ask whether someone would show the class the sun through a solar telescope.

ACTIVITY 4

Exploring the Brightness of Stars

Purpose

To understand why some stars in the sky look brighter than others.

Material

Three flashlights, two the same size, and the third a different size (larger or smaller does not matter). (This activity could work just as well with three balls: two the same size and color, and one larger and brighter or smaller and darker than the others.)

Translucent sheets of white paper, such as wax paper.

A corner of the room that can be darkened slightly.

Matter and Astronomy Journal and pencils.

Presentation

- Most Montessori teachers introduce this concept in Year 2 or 3.
- Before the presentation, cover the flashlight lenses with the white paper, so they produce a uniform but still bright white light rather than a glaring light.
- Announce to the students that they will be studying why some stars appear brighter in the sky than others.
- Take the students to a corner of the room that can be darkened.

REVIEW

- With the students, review how stars form.
- Invite the students to describe how the stars in the night sky appear in terms of size and brightness (some appear much brighter than others, some look whiter, and some redder). Discuss reasons why this might be the case (some stars are closer to the earth, and some are larger and hotter than others).

LUMINOSITY

- Define and discuss luminosity (measure of the amount of light energy produced by a star).
- Present the two flashlights that are the same size and brightness, and explain that they represent two stars of equal size and brightness in the sky. Darken the corner of the room, then shine the two flashlights at the students from the same distance away.

- Ask the students to observe the two lights, representing two stars that are the same size and brightness and the same distance from earth, and describe how they would appear in the night sky (the same).
- Position the lights so that one is farther away from the students. Invite the students to say what happens when two stars of the same size and brightness are different distances away.
- Put one of the flashlights aside.
- Present two flashlights, one bigger than the other, and explain that they represent two stars in the sky, the one larger and brighter than the other. Shine the two lights at the students from the same distance away. Invite the students to say how two stars the same distance away appear when one star is larger and brighter than the other.
- Position the brighter light closer than the other light. Ask the students to say which light will appear brighter here on earth for each position.
- Then position the brighter light farther away and ask the same question.
- Ask the students to use their journals to draw illustrations showing three stars of different sizes and brightness at different distances from the earth, labeling which are brightest in the sky.

Extensions

- In a paragraph, explain why one star might give off more light than another star.

ACTIVITY 5

Exploring the Life Cycle of a Giant Star

Purpose

To understand the life cycle of a giant star.

Material

Illustration: Giant, yellow dwarf, and supergiant stars.

Illustration: Supernova 1987A.

Illustration: Possible life cycles of a star.

Matter and Astronomy Journal and pencils.

Presentation

- Most Montessori teachers introduce this concept in Year 3.

- Announce to the students that they will be studying the life cycle of a giant star.

REVIEW

- Present the illustration, Possible life cycles of a star. With the students, review the life cycle of an average star, including the red giant and white dwarf stages.

GIANT

- Explain that if there is plenty of gas and dust in the nebula, it is possible for giant stars, stars that are much bigger than the sun, to form.

- Present the illustration, Dwarf, giant, and supergiant stars. Point to the smallest star and explain that it represents the sun. Point to the giant star and explain

that stars sometimes form that are this much bigger than the sun.

GIANT TO SUPERGIANT

- Explain that because it is so big, the heat and pressure in the core of the giant star are much greater, so that it converts its hydrogen to helium in a very short period of time compared to an average star, often only a few million years. When a giant star starts to run out of hydrogen, it becomes a supergiant. Present the illustration, Dwarf, giant, and supergiant stars. Point to the supergiant star.

SUPERGIANT TO SUPERNOVA

- Explain that when the supergiant star runs out of fuel, it will explode in a supernova, brighter than a million stars. Present the illustration, Supernova 1987A.

- Explain that if the original giant star was smaller than twenty times the size of the sun, it would become a neutron star, a tiny star the size of a large city.
- Explain that if the original giant star was larger than twenty times the size of the sun, it would become a black hole, a tiny object about the same size as a neutron star, but much, much heavier. Explain that the black hole is so heavy that its gravity will not let light escape, the way a light bulb with a coat of thick paint that will not let any light out. The black hole is creating light just like a neutron star is, but its gravity holds the light inside.

SUMMARY

- Present the illustration, Possible life cycles of a star, and with the students trace the life cycle of a giant star.
- Ask the students to use their journals to draw and label an illustration showing the possible life cycle of a giant star.

Extensions

- Write a paragraph explaining what allows a star to form that is so much bigger than a normal star.
- Research black holes, then write a short report on what they are and what makes them interesting.
- Research black holes, then write a report explaining how astronomers know black holes exist if they do not shine.