



Big Picture Science Newsletter

The science information newsletter for Montessori teachers of 6-15 year-olds

The Stars, part 2

The book and other references that I list in my newsletters are ones I have found to be accurate and appropriate for classrooms. I don't list the many that I reject. This time I'd like to note one book that I would not use in an elementary class. That is Couper and Henbest's *Black Holes*, published by DK. It has so much fantasy and science fiction mixed with the information that I think it would confuse children more than enlighten them.

It is important for children to know the basis for the information we give them. In this issue I have given some of the methods we use to learn about stars. Remember to include how we know what we know in all your science studies.

From here, I will move closer to home for the next newsletter, which will address the origin of the solar system and Earth.

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Stellar Evolution & Measuring Stars

Help students find how we know what we know about stars

Stars have different patterns of death depending on their mass. But how can we measure the mass of a star or its distance from Earth? The story of how we measure the stars shows a classic application of scientific reasoning.

When astronomers speak of stellar evolution, they are not talking about stars slowly changing into another type of species, as biologists might use the term. For stars, the term "evolution" has its more general meaning, which the dictionary gives as "a process of change in a certain direction". **Stellar evolution is simply the changes a star undergoes throughout its life cycle.**

There are **four main scenarios**. Like many other attributes, the events of a star's death are **dependent on its mass**. For stars with **less than 0.8 of the Sun's mass**, there isn't much drama. Astronomers think that these stars brighten, then **gradually cool and dim** when they run out of hydrogen. We aren't sure how these stars die because they live longer than the present age of the universe.

The fate of stars with **0.8-10 times the Sun's mass** includes formation of a **planetary nebula and a white dwarf**. Stars of **10-20 times the Sun's mass** have more violent deaths. They **end in supernova explosions** and leave **neutron stars** as their last remnants. The rare giant stars **more than 20 times the Sun's mass** also form supernovas, but their last remnants are **black holes**.

I give you several good references on black holes, but will not discuss them in detail. There is so much misinformation and speculation about these mysterious objects that you will certainly need to **help your students sort fact and fiction**. Remind them that to study something scientifically, we need to be able to observe and measure it. There are measurable physical phenomena associated with black holes, even if we can't directly see them. We also have information from theoretical physics, which is founded on experiments we can do here on Earth.

An aspect of stellar evolution that is often omitted from books is that the outer layers of dying stars are shed into the surrounding space and give rise to new stars. There is a majestic, slow **cycling of matter from generation to generation of stars**.

Your students may wonder how we can predict so much about the stars and how we know so much about how they work. Chapter 10 of John Gribbin's book, *Almost Everyone's Guide to Science*, summarizes how we know so much about stars. It is written for adults, and so will need simplifying for elementary students. ★

The Ending of Stars' Life Cycles

The events of a star's ending, like its main sequence position, are governed by its mass. First there is the fate of stars that have about 0.8-10 X the mass of our Sun, including the Sun itself. Then there are the stars with 10-20 solar masses. The rare stars that have greater than 20 times the Sun's mass have yet another fate. Let's see how a reporter would tell their stories.

NEWS FLASH from the GALACTIC TIMES: *The beginning of the end for a yellow star*

A yellow G-class star in the Perseus Arm of the Milky Way Galaxy is departing the main sequence! After 10 billion years of fusion, this Sun-like star has **run low on hydrogen in its core** and its own **gravity is causing the core to contract**. The star is fighting back. In a **shell** around its shrinking core, hydrogen has become very compacted and heated to the point of fusion. This is allowing it to hold off gravitational collapse for now. You might think that our star would dim, but just the opposite has happened. The energy released from the hydrogen-fusing shell and the contracting core is causing it to get **bigger, redder, and brighter**. Its outer layers have swollen to nearly a hundred times their main sequence size and have engulfed its inner planet! Its core has shrunk tremendously. It has been transformed into a **class M giant**. What can we expect from this unstable elderly star? Its hydrogen can't last much longer!

Our astronomers have observed many stars of this mass at all stages in their lives. They predict that next we will see the star will resort to **fusing helium in its core**. This starts when the core contracts and reaches **temperature of 100 million K**. That's ten times hotter than the temperature needed to fuse hydrogen, but it takes that sizzling temperature to bring helium's positively charged nuclei together. The strong force needs a very close approach to grab and bind the nuclei.

The star's outer layers will contract as its energy output stabilizes and for a brief period it will be an **orange giant of the K class**. But that won't last. It took the star 10 billion years to use the hydrogen in its core. The **helium will only last about 50 million years**. Then all of its helium will be fused into carbon and oxygen. Gravity will put the squeeze on and the star's core will contract, but it can't get hot enough to fuse any more elements there. Its **outer layers will swell** tremendously – to **500-1000 times its main sequence size**, frying its inner planets. (The inhabitants should have left millions of years before this. The star got hotter all throughout its

lifetime and overheated the inner planets even before it left the main sequence.)

The star will be really **unstable** at this time. Its **outer layers will be pulsating and spewing out** into the heavens, as it does a short stint as a Mira-type variable star. It will likely go through a series of belches a hundred or more days apart. The resulting **dust-rich nebula** will be great boon to nearby star formation, since it shields gas clouds from the heat of other stars. Even as our star is dying, its **outer layers will give birth to new stars**.

What will be our star's last act? Be sure to watch! This will be spectacular, but it won't last for much more than 50,000 years. As the outer layers of the star are leaving, its **core will contract, heat to over 25,000 K**, and pour out **ultraviolet light**. The high energy photons will ionize the gas and dust shell around the core and produce one of the jewels of the universe, a colorful **planetary nebula**.

"Planetary nebula" is one of those confusing terms left over from early astronomers, who didn't have much in the way of telescopes. They thought that the rings of gas looked something like the planets Neptune or Saturn. These nebulae don't have anything to do with planets; they are the glowing outer layers of the dying star.

At the center of the planetary nebula, the remains of our star will be a white-hot core, and gravity will get the upper hand. The **core will contract until it is only about 1/100th** of the star's main sequence diameter. Gravity will have crushed its core from a density of about 140 grams per cubic centimeter (cc) to an astonishing **million grams per cc**. Compare that to the density of a typical rocky planet surface – 3 grams per cc – and you begin to see just how dense the last remains of our star will be. A teaspoon of the contracted core weighs as much as a truck!

How in the universe can something get that dense? Well, it isn't so hard if you just squeeze the matter until the electrons touch. Two electrons will fit in the same place if they have different spins, but after that, more electrons can't be

smashed together. It takes much more gravity than a yellow star has to force further contraction. After all, it loses 40% of its mass when its outer layers go.

What's left will be a **white dwarf star**.

Astronomers are masters of confusing names. White dwarf stars are totally different from regular dwarf stars, which is another name for the main sequence stars. White dwarfs are much smaller and denser, and to top it all off, they don't have to be white! They start blue-white hot (and I do mean hot – temperatures up to 200,000 K – the

hottest stars in the sky!), but gradually cool to yellow, orange, and then red. The current thinking is that they will eventually cool to cold black objects called **black dwarfs**, but no one has been around long enough to see this. It may take trillions of years.

For now, stand well back, enjoy the fireworks, and cheer on our aged star as it cycles its matter to the next generation..... Now we'll move on to a report from the other side of the galaxy, where a much bigger star is reaching the end of its life. *

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NEWS FLASH from the GALACTIC TIMES: The imminent death of a blue star

Stand well back! What used to be a large, deep blue star is changing really fast! Our star has lived fast and now it is rapidly approaching the end of its life. Astronomers predict that it may explode in a big way soon. "Soon" as astronomers define it, that is, which means within the next 10,000 years. Let's go back and see how our star got itself in this condition.

This **O-class star** started with about **15 times the mass** of the yellow G-class star. Its birth nebula compacted rapidly and it began to shine in only a couple of million years. Compare that to the 50 million it took our yellow star to form. Our blue star spent only about 10 million years on the main sequence, fusing hydrogen in its core. When it began to **run out of hydrogen** fuel in its core, it **fused hydrogen in a shell** around its core and swelled as it became a red giant. This star, however, heated up enough to start **core helium fusion** even before it fully entered the red giant stage. Now its inside is like a layer cake, with the heaviest elements in the center. We'll look more at that shortly.

This star didn't become a mere red giant. It became a red **supergiant** after passing through white, yellow, and orange supergiant stages. Supergiants are so big that if a large one was put in the Sun's place, its surface would reach all the way out past the orbit of Jupiter! They have radii of 100-1000 times bigger than the Sun. The star Betelgeuse in the constellation Orion is one of these red supergiants.

Our massive star went through a period of **instability and pulsed** as it shed most of its outer layers. It was a Cepheid variable star (see p. 6) for a while as it fused helium. It **shed** even more of its mass than the yellow star did, puffing off **more than 80% of its original material**. At

this point, the **mass left in the core is the important thing**. This star is over the Chandrasekhar limit. That's named after the Indian astronomer who discovered it. Stars with core masses of more than 1.4 times the total mass of the Sun can't form white dwarfs. Their gravity is too strong for the pressure of the electrons. These stars collapse even further.

What do you get when you squeeze electrons and protons really, really hard? You get neutrons (and neutrinos, which fly away). When the core of a large, blue star collapses, it becomes a rapidly spinning **solid ball of neutrons**, something like the nucleus of an incredibly huge atom. This is called a neutron star and it is so dense that a teaspoon of it weighs as much as a mountain. Its **density is about a billion tons per cc**. The neutron star is only about 10 km across, even though it started out with 1.4 times the mass of the Sun or more. In contrast, the white dwarf could form from the Sun will be the size of the Earth, about 6000 km across. The youngest neutron stars are also called **pulsars**, since we can detect pulses of radio waves from some of them.

So what can squeeze a star's core so hard that it turns into pure neutrons? Gravity can, if there is nothing to oppose it. Our star hasn't collapsed yet, so something is opposing gravity for now. If we could look inside this star's core, here's what astronomers think we would see. It would have a structure something like the **layers** of a cake, only spherical. From the outside, the layers are: helium; carbon and oxygen; magnesium, neon, sulfur, and silicon; and in the center, eventually, there is a huge iron ball. The inner layers form faster and faster. Helium fusion supported the star for about a million years. Carbon fusion lasted about a thousand years, and oxygen will be

fused in about a year. The **iron core forms in only about a week.**

Iron cannot release energy, either by fusing or by splitting (fission). Gravity is still squeezing hard. Something has to give. In this case, it is nearly the whole star. In a catastrophic **supernova** explosion, the **iron core collapses** from the size of the Earth to only kilometers across in less than a tenth of second! The **core rebounds** and for an instant, it releases a shock wave with more energy than a normal galaxy of

stars. In that great shock wave, all the remaining **outside of the star is blown away and all the chemical elements form**, including those needed for life.

Thank goodness that there are these huge supernovas to make the elements we need for life and thank goodness they are rare. One may have started formation of the Sun and its planets, but another anywhere near would mean disaster. Luckily there aren't any O-class stars in our neighborhood, so we don't have to worry.*

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How do we know that neutrons stars are so small and dense?

The laws of physics tell us that if **something is rotating very fast, it must be very small** or else the angular momentum would break it apart. There is a neutron star in the Crab Nebula, the remains of a supernova explosion in the year 1054. It sends out more than **30 pulses of radio waves each second.** This means that it is spinning 30 times a second, so it has to be small. Astronomers can estimate the mass of neutron stars that are part of binary systems (see below). Since these stars are **very small** (on the order of kilometers in diameter) and **very massive** (1.4-3.0 times the Sun's mass), that **means they must be extraordinarily dense.** Ordinary matter can't be that dense, so we are left to hypothesize that these stars are pure neutrons packed together. Don't plan on sending a space ship to land on one and study it, however. The craft would be smashed to the thickness of a single atom by the enormous surface gravity.

Key concept for understanding black holes: Escape velocity

Escape velocity: the speed at which something must travel to leave the gravitational pull of a celestial object.

The escape velocity for Earth is 11.2 kilometers per second. If you were much farther from the center of the Earth, in a space ship orbiting the planet, you would have a much smaller escape velocity. If the Earth were compacted smaller, at the surface the force of gravity would be stronger and you would need to travel faster to escape the planet. If you could squeeze the Earth down to the size of a marble, the surface gravity would be so strong that even light, which travels at about 300,000 km/sec, would not be able to break away. The Earth would be a mini-black hole. Earth's gravity isn't strong enough to compact it so small, but the cores of huge stars do have gravity that strong. Stars that have more than about 20 times the Sun's mass and whose cores have more than about 4 times the Sun's mass end their lives as black holes. See the references for more information on black holes.

To model escape velocity, see Janice VanCleave's *Astronomy for Every Kid*, Activity 94, Escape.

How can we measure the mass of a star?

Astronomers certainly can't put a star on a huge scale and weight it, so how do they determine the mass of a star? In astronomy, nature does the experiments and scientists have to observe carefully to see the results. Binary star systems are the key to determining star masses.

To understand this, you need to understand the concept of center of mass. The center of mass is a point in a rotating system that acts as if all the mass were concentrated there. See the demonstration on p. 7.

In binary star systems, the two stars orbit around their center of mass. If one star is more massive, the center of the orbit is nearer to it. By measuring the orbital period, the time it takes for the two stars to complete one orbit and measuring the distance they are apart (see p.6), astronomers can calculate the masses of the stars. They use a law of motion that Johannes Kepler discovered.

When astronomers had determined the masses of many stars, they had enough data to know that a main-sequence star that is yellow, like the Sun, has about the same mass as the Sun. For main-sequence stars that aren't binaries, the mass is estimated from the luminosity and the spectrum. The spectrum is measured with the spectroscope. Luminosity is calculated from the star's apparent brightness and its distance. Measuring the distance to the stars was a key step for astronomy.

How do astronomers measure the distance to a star?

There are several overlapping methods, depending on the distance range from Earth.

❖ Measuring the distance to the nearest stars with trigonometry

The first accurate measurement of the distance to a star occurred in 1838. The German astronomer Friedrich Bessel determined that the star 61 Cygni was about 11 light-years from Earth. The method he used is called **parallax**. For a well-written, adult-level account of the discovery, with great stories of the people involved, see Alan Hirshfeld's book, *Parallax: The Race to Measure the Cosmos*.

Parallax is the apparent shift in position that we see when we view an object from two different places. You can easily see it with a simple demonstration. Hold your finger out about a foot in front of your face and look beyond it to a distant object. Close each of your eyes alternately. You should see your finger's image shift from side to side. You can see a difference if you hold your finger closer or farther away. If you measured the distance between your eyes and the angle formed by a line from each eye to the image, you could calculate the distance to the finger. This will likely be easier to see with the demonstrations on p. 6.

To measure the parallax of a star, astronomers make observations 6 months apart, so that the **orbit of the Earth is used as the baseline**. (The distance between your eyes is the baseline in the demonstration above.) The shift in the star's apparent position is measured in arc-seconds, $1/60^{\text{th}}$ of an arc-minute and $1/3600^{\text{th}}$ of a degree of arc. The measurements are given in parsecs, which stands for parallax seconds of arc. A parsec is equal to 3.26 light-years.

Astronomers observing from the Earth's surface have used **parallax to measure stars that are within 100 light-years of Earth**. The satellite Hipparcos (**H**igh **P**recision **P**arallax **C**ollecting **S**atellite) made much more accurate observations, since it didn't have to look through the Earth's distorting atmosphere. It measured the parallax of stars that are **more than 300 light-years** away, operating from 1989-1992. Several more star-surveying satellites are in planning.

❖ Cepheid and RR Lyrae variable stars

Giant stars that are becoming red supergiants go through a stage when they are yellow. During this time, some of them become variable stars that regularly brighten and dim in a measurable and characteristic way. This type of variable is called a **Cepheid** [seh-FEE-id] **variable**, after the first one discovered, Delta Cephei, in the constellation Cepheus. In the early twentieth century, Harvard astronomer Henrietta Leavitt discovered that the time interval a Cepheid variable takes to brighten and dim (called its period of variation) is depends on its actual luminosity. This important discovery allowed astronomers to calculate **the distance to stars in nearby galaxies**. When you know the actual luminosity of a star and you can measure the apparent luminosity (how luminous it appears from Earth), you can calculate how far away it is using the inverse-square law. (See the Internet sites, p. 8, for a demonstration of the inverse-square law.)

The **RR Lyrae variable** stars have a characteristic pattern of change that lets astronomers positively identify them. They all have nearly the same luminosity, so they, too, allow astronomers to determine their actual distance. They pulse over periods of $\frac{1}{2}$ to 1 day, compared with the Cepheid variables, whose periods of variation range from 1-100 days.

❖ Spectra of main-sequence stars – "Spectral parallax"

This method has another of those confusing names. It has nothing to do with trigonometric parallax. It estimates distances from the spectrum of the stars. The average luminosity of main sequence stars in each spectral class is well-known, from studies with parallax and measurements of brightness. If an astronomer spots a star that has the same spectrum as the Sun, she can assume that it has about the same luminosity, provided it is a main sequence star. From that information, she can calculate the distance, again using the inverse-square law. The width and kind of the lines in the star's spectrum help astronomers tell if it is a giant or a main sequence star.

❖ Red shift, the key to really big distances

When astronomers need to measure something that is really distant, like the far galaxies, they use red shift. This is like the Doppler shift that we can hear in sound waves as a train passes, with the frequency rising as the train approaches and falling as it passes. The spectra of distant objects have the lines shifted toward the red end of the spectrum. Edwin Hubble used this kind of information to determine that the universe is expanding and that most galaxies are moving away from us.

How do we know the diameter of a star?

Even with high-power telescopes, stars look like points of light. Astronomers measure stars' diameters using optical interferometry. This technique uses a computer to combine the light from several telescopes and look for differences in wavelength. See <http://www.sciam.com/2001/0301issue/0301armstrong.html> for more details. The orbits of binary stars can be measured this way as well. The diameter of stars can also be estimated using a law of physics (Stefan-Boltzmann law). This law states that the luminosity of a star is proportional to its radius squared and its temperature to the fourth power. (See Newsletter #19 for how we measure a star's temperature.)

Parallax demonstration - beginner

You need: a table, a meter stick, a ruler, a long strip of paper, small adhesive dot, and a paper clip.

Preparation: Mark parallel lines that are 10 cm apart and at least 10 cm long on the large sheet of paper. Use a thick line that shows up from a distance. Number the lines at the top. Hang the paper on the wall at least 3 meters (10 ft) from a table. Lay the meter stick down on the table, perpendicular to the wall. Make a "star" holder by bending half of the paper clip at a right angle. Stick the dot on the end of the holder.

What you do:

- Set the holder on the meter stick so that the dot is at 25 cm.
- Place your nose at the end of the meter stick where you can see the lined paper on the wall.
- Close one eye and notice the number of the line where the dot aligns. Now close the other eye. (If students have trouble with this, give them a note card to hold in front of their eye.) The dot seems to move. Note the number of the line where it now appears.
- Subtract the larger number from the smaller one to see how far (how many marks) the image moved.
- Repeat this with the dot at the 50 cm and 100 cm marks.

You should be able to see that the farther away the dot is, the smaller its apparent motion against the background when you look with each of your eyes separately.

Parallax demonstration – advanced

You need: a protractor, a meter stick, a strip of shelf paper at least 65 cm long

What you do:

- Measure two points, 20 cm apart at the short edge of the strip of paper. Label these points A and B.
- Make a mark half way between them at 10 cm.
- Draw a line perpendicular to the short edge of the paper through the 10 cm mark. Make this line at least 60 cm long. We will call this line C.
- Make marks on line C at 20 cm, 40 cm, and 60 cm from the edge of the paper. These are your "star" positions.
- Draw lines from points A and B to the 20 cm, 40 cm, and 60 cm marks. These show the light path to the observer.
- Measure the angle formed by the outside line and line C at each of the marks. (Note: these angles should be roughly 26.5, 14, and 9.5 degrees.) The farthest "star" has the smallest parallax angle.

What it means: If you were an astronomer taking observations from points A and B, you could calculate the parallax angles using trigonometry. On your paper, you measured degrees of arc. Astronomers measure arc-minutes and arc-seconds. The parallax of stars is less than an arc-second. No wonder it took so long for someone to measure this. They had to have very accurate instruments.

Demonstrating apparent brightness

You need: two identical flashlights, a long darkened hall

NOTE: This is a tricky demo. If it won't work for you with flashlights, try clear Christmas mini-lights. Our eyes change their perception of light, so they aren't the best instrument to measure intensity.

What you do: Three people do this as a team. One, whom we will call the observer, stands at the end of the hall. The other two hold the flashlights and shine them toward the observer, but not in the person's face. Start with the flashlights at the opposite end of the hall. Then have one light carrier walk slowly forward. The observer should see that the far light looks dimmer. If you are using Christmas mini-lights, furnish an extension cord so that the lights can be moved back and forth.

What it means: When an astronomer sees a bright and dim star together in the sky, she must determine if one star is actually smaller and dimmer or if it is just farther away. If she can find the actual luminosity (brightness) of the star and measure its apparent brightness, she can calculate the distance to it.

Demonstrating the center of mass

- When two objects orbit one another, the point around which they rotate is their center of mass. You can use a dowel and clay to explore the center of mass.

You need: a piece of dowel about the diameter of a pencil and about 10 inches long (or use a new pencil), modeling clay, a piece of yarn or string with a loop tied on one end.

What you do: Slip the dowel through the loop in the string. Stick a large ball of clay on one end of the dowel and a slightly smaller ball at the other end. Lift the dowel using the string, place your other hand under the dowel, and slide the yarn back and forth until you find a point that balances the masses of the two clay balls. Hint – Slide the yarn toward the end that goes down. The dowel should be level. Gently twirl the dowel. If it swings evenly and stays level, you have found the center of mass for the two clay balls (and the dowel). Try this with nearly equal and unequal masses and observe the shape of the orbits.

Resources for star study

Books for children about the stars – See Dewey Decimal numbers 520, 523.

- Allan, Jerry and Georgiana Allan. 2000. *The Horse and the Iron Ball: A Journey through Time, Space, and Technology*. Lerner Publications Company. ISBN 0-8225-2158-X. This is a “must-have” book. It is a beautiful introduction to stellar nucleosynthesis and an example of what children’s science books should be – beautiful, imaginative, and informative. LE-UE, adults and MS will enjoy it, too.
- Gallant, Roy A. 2001. *Stars*. Kaleidoscope series. Benchmark Books. ISBN 0-7614-1036-8. A good introduction to the subject, including the end of stars’ lives. LE-UE
- Gallant, Roy A. 2000. *The Life Stories of Stars*. (The Story of Science series) Benchmark Books. ISBN 0-7614-1152-6. This book offers a thorough look at stars, from the history of astronomy to the stellar life cycles and the fusion reactions that run them. The chapter on measuring the distance to stars is great. UE-MS.
- Gallant, Roy A. 1998. *When the Sun Dies*. Marshall Cavendish. ISBN 0-7614-5036-X. A thorough treatment of the workings and predicted death of the Sun, it includes the fate of other stars as well. MS – adult
- Mitton, Simon and Jacqueline. 1995. *The Young Oxford Book of Astronomy*. Oxford University Press. ISBN 0-195214455. This is my pick for an astronomy reference for UE-MS. It has the physical science background and a very useful explanation of parallax. The diagram of stars’ life cycles is the only one I have found that shows the recycling of material from one generation of stars to the next.
- Newton, David E. 1997. *Black Holes and Supernovae*. Twenty-First Century Books. ISBN 0-8050-4477-9. Good coverage of the history and theory of black holes. UE-MS
- Scagell, Robin. 1996. *Space Explained: A Beginner’s Guide to the Universe*. Henry Holt Reference. ISBN 0-8050-4872-3. The star chapter of this book includes star life cycles, a 3-D diagram of a constellation, and a useful explanation of black hole formation. UE-MS
- Scott, Elaine. 1998. *Close Encounters: Exploring Space with the Hubble Space Telescope*. Hyperion Books of Children. ISBN 0-7868-2120-5. The chapter on star death explains black holes clearly and has good illustrations. The actual photo of a Sun-size star in its last stages is great. UE-MS
- Sipiera, Paul. 1997. *Black Holes* (A True Book). Children’s Press. ISBN 0-516-20326-6. Although the text is large type and looks like beginner level, the information is quite sophisticated. Advanced LE-UE.
- Stannard, Russell. 1995. *Our Universe: A Guide to What’s Out There*. Kingfisher. ISBN 1-85697-551-7. This book has good explanations of how stars work and their life cycles. UE-MS
- Vogt, Gregory L. 1999. *Deep Space Astronomy*. Twenty-First Century Books. ISBN 0-7613-1369-9. The basic description of planetary nebulae, neutron stars, and black holes is very understandable. UE-MS

Magazine articles

- “Our Once & Future Sun” *StarDate Magazine*, Nov/Dec 2001, pp. 16-19. This magazine for general readers is published by the University of Texas at Austin McDonald Observatory. You can subscribe at 1-800-STARDATE. UE-adult. StarDate online is at: <http://stardate.org>
- Larson, Richard B. and Volker Bromm. “The First Stars in the Universe” *Scientific American*, Dec. 2001, pp. 64-71. This adult-level article is an interesting extension of star study and a good bridge between the early universe and stars.
- Svitil, Kathy A. “A Spectral Look at an Alien World” *Discover Magazine*, Feb. 2002, p.16. This article is illustrated with the solar spectrum. The dark lines are absorption lines of elements in the Sun’s atmosphere. This shows how complex the spectra of stars really are.

Books for adults and reference

- Berman, Bob. 1995. **Secrets of the Night Sky**. HarperPerennial. ISBN 0-06-097687. The casual tone makes this easy reading. The chapter on black holes provides useful explanations and analogies. MS-Adult
- Clark, Stuart. 1995. **Stars and Atoms: From the Big Bang to the Solar System**. Oxford University Press. ISBN 0-19-521087-5. This is a good place to go when students need more in-depth information. The sections on post-main sequence events are useful. HS-Adult
- Croswell, Ken. 1999. **Magnificent Universe**. Simon & Schuster. ISBN 0-684-84594-6. This large hardback provides easy-to-read text and wonderful illustrations (good for all levels). The examples of planetary nebulae are great. The descriptions of stars' deaths are very good. MS-Adult
- Dickinson, Terence. 1999. **The Universe and Beyond**. 3rd ed. Chapter 5. "Cosmic Furnaces". A Firefly Book. ISBN 1-55209-377-8. This book has drawings to help one imagine how exotic stars would look. A diagram shows the color and size of the nearest stars to the sun. Good coverage of star death and black holes for HS-adults.
- Gribbin, John. 1998. **Almost Everyone's Guide to Science**. Yale Nota Bene. ISBN 0-300-08460-9. Chapter 10, "The Lives of Stars" is a good introduction to how we know what we know about stars. HS-Adult
- Raymo, Chet. 1982. **365 Starry Nights**. A Fireside Book by Simon & Schuster. ISBN 0-671-76606-6. This classic provides a very readable introduction to stars. The glossary is indexed to the text. See the June 4 entry for parallax information. See January 5 and 6 for an explanation of the angular method of measuring the sky, which is helpful for understanding parallax measurements. UE-Adult
- Tyson, Neil deGrasse, Charles Liu, and Robert Irion. 2000. **One Universe: At Home in the Cosmos**. Joseph Henry Press. ISBN 0-309-06488-0. This has a good diagram that shows stars of different masses and their life cycles side-by-side. It also has good information and diagrams on supernovas and stellar nucleosynthesis. HS-Adult

Internet sites:

Information about Henrietta Leavitt, discoverer of Cepheid variables
<http://www.pbs.org/wgbh/aso/databank/entries/baleav.html>

Astronomy Society of the Pacific's electronic newsletter for teachers. The educational activities links are also valuable.
<http://www.astrosociety.org/education/publications/tnl/tnl.html>

NASA's Imagine the Universe, site map. You can click on black holes or neutron stars for information at several levels.
<http://imagine.gsfc.nasa.gov/docs/sitemap.html>

An activity for elementary or middle school on star color and luminosity
<http://www.seti-inst.edu/planetsy.html>

Star Light, Star Bright from Amazing Space – interactive tutorial for kids. Click the Amazing Space icon for more activities, including one on black holes
<http://amazing-space.stsci.edu/light/index.html>

Information about women astronomers
http://www.astrosociety.org/education/resources/womenast_bib.html

From James Kaler's Astronomy text website
http://www.astro.uiuc.edu/~kaler/sow/star_intro.html

Mr. Galaxy's Introduction to Supernovae
http://www.chapman.edu/oca/benet/intro_sn.htm

Scientific American's Ask the Experts: How do we know the life cycle of stars?
<http://www.scientificamerican.com/askexpert/astronomy/astronomy26/astronomy26.html>
<http://www.scientificamerican.com/askexpert/astronomy/astronomy7.html>

Stellar distances from Cambridge. Click on "parallax" for illustrations of this phenomenon.
<http://www.ast.cam.ac.uk/~mjp/index.html>

Information on Cepheid variables from University of Oregon
<http://zebu.uoregon.edu/~soper/MilkyWay/cepheid.html>

For a good activity to explore the inverse square law, see:
http://www.exploratorium.edu/snacks/inverse_square_law.html

Other resources:

The Astronomical Society of the Pacific offers a variety of educational products for all ages. You can request a catalog at 1-800-335-2624. Be sure to take a look at their elementary-level activities guide, *The Universe at Your Fingertips*. This organization has a wonderful selection of posters. Their on-line catalog is at:
<https://www.mailordercentral.com/apsky/>