

WHEN STARS GO BOOM

Facilitator's Guide • Section 1.1



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INTRODUCTION

Students of almost all ages have some awareness of the nighttime stars, and many are aware of the fact that the Sun is one such star. Because we do not see obvious changes in stars on timescales of days or even years, most students don't give much thought to the question of how long stars last, and what happens to them when they stop shining. "When Stars Go Boom!" introduces several key ideas about stars, and focuses in particular on the supernova explosions that mark the ends of the lives of the most massive stars. The poster provides a particular example of one such supernova that occurred in 1987, explaining briefly how the explosion was discovered (by a student) and how the most advanced telescopes in the world are currently used to study the effects of the explosion. The idea is extended to a stellar explosion that occurred in the year 1054, as recorded by ancient astronomers, and whose remnants can still be seen in a telescope today.

The primary points covered in the poster are:

- The sun is a star. Despite an awareness of a multitude of stars in the night sky, students often do not make the connection that the Sun is one such star.
- Stars live a long time, but not forever. Stars like the Sun, for example, have typical lifetimes of about 10 billion years.
- Bigger stars live shorter lives than smaller stars. Here, by "big" and "small" we mean stars with large or small amounts of mass.
- The most massive stars end their lives in massive explosions, called supernova explosions (or supernovae). The Sun is not such a star; it has a modest mass and will not explode at any time in its life. However, stars that are more than about 10 times as massive as the Sun undergo extremely bright explosions.
- The energy of a star is supplied by gravity. The same force that causes an apple to fall from a tree, and the Earth to orbit the Sun, pulls the gas that makes up the Sun toward its center. The gas is heated as it is compressed, with the central region reaching temperatures of more than 15 million degrees.
- When the fuel runs out at the center of the star, gravity makes it collapse. For stars like the Sun, the center gets crushed down to something about the size of the Earth. For much more massive stars, the gravity is so strong that the center is crushed to the point where a violent explosion occurs.
- We actually observe stars explode. That last one that was relatively nearby was in 1987. We have pictures of the sky from before and after the explosion. The original star is now gone, and we now see a hot shell of gas from the explosion.
- We can also find the relics of stellar explosions from long ago. Some—like the Crab Nebula—were recorded by ancient astronomers. We can still see these objects with telescopes. Astronomers study these objects to learn about how stellar explosions affect the structure of our Galaxy, and to understand how matter behaves when it has been crushed to extremely high densities.

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BACKGROUND SCIENCE

Gravity is perhaps the most familiar of the fundamental forces. We feel its effects when we climb the stairs, lift a growing child, or haul a bag of books back to the library. The pull is relentless. It is also universal. Every bit of matter exerts a gravitational pull on every other bit of matter in the Universe. While the strength of the force decreases rapidly with distance, it is still sufficiently strong to pull together massive clouds of gas and dust in interstellar space. As the clouds contract under the pull of gravity, the temperature increases as a result of collisions between individual atoms or molecules. In regions where the densities of the clouds get sufficiently high, stars can form. This occurs when the temperature gets high enough to initiate the fusion of hydrogen into helium. Energy is released in such a reaction, and this energy supplies pressure that can halt the gravitational contraction—at least temporarily. Think of it as floating in a swimming pool. The pressure of the water on your back is enough to keep you floating 10 feet above the bottom of the pool despite the pull of gravity. Until someone drains the pool...

The hydrogen at the center of a star can't last forever. Eventually it is all converted to helium (and smaller amounts of a few other elements) and the pressure support goes away, causing gas to free-fall toward the center of the star again. If the star is massive enough, the gravitational pull can be sufficient to generate temperatures high enough for helium fusion, again temporarily providing a pressure support against gravity. This process of fusion, fuel depletion, collapse, and new fusion can continue for a while, but not indefinitely. For the most massive stars (10 or more times as massive as the Sun), the process can be driven all the way to the point that the center of the star is an ultra-hot gas composed of iron. But when iron nuclei are fused together, they don't release energy. So, if a star gets to the point where it forms an iron core, it is in trouble. Big trouble. The huge gravitational forces in these massive stars commence to crush the core of the star in less than a second, triggering a massive explosion called a supernova. The explosions release so much energy that they can be observed (with telescopes) in very distant galaxies, where they briefly outshine the combined light of all the other stars in the host galaxy.

Our Sun is not massive enough to ever become a supernova. It has been fusing hydrogen into helium for about 5 billion years, and will continue to do so for about another 5 billion years before following an interesting (perhaps the subject for another poster!) but much less spectacular death. The most massive stars, which live much shorter lives (only millions or tens-of-millions of years), go out with a bang!

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FUN FACTS

- Studies of other galaxies lead us to believe that a supernova explosion occurs about once every fifty years in our own Galaxy (the Milky Way). However, the last one actually observed in our Galaxy was Kepler's supernova, in 1604. It may be that others have occurred in very distant, dusty regions that are obscured from our view, but nobody knows for sure if this is why we haven't seen any more recently. Maybe we are overdue for a nearby supernova!
- Supernova 1987A gets its name because it was the first one observed in the year 1987. The next was SN 1987B, which is much less famous because the explosion was 600 times further away, in the distant galaxy NGC 5850. SN 1987A occurred in a small neighbor galaxy of our own Milky Way.
- The dwarf galaxy in which SN 1987A resides is called the Large Magellanic Cloud (LMC). It can be seen with the naked eye in the southern hemisphere and is named after the explorer Ferdinand Magellan, who discovered it on his expedition of 1519 (though other, earlier explorers had also recorded observing it).
- When a supernova explodes, it briefly outshines the light of all the other stars in the galaxy in which it resides.
- At the center of the Crab Nebula resides the crushed core of the star that exploded in 1054. It is about one and a half times as massive as the Sun, but only about 10 km (6.25 miles) in diameter. It spins around 30 times each second!
- The bright red star Betelgeuse, in the constellation Orion, is about 20 times more massive than the Sun. Betelgeuse will eventually end its life in a supernova explosion!
- Most of the gas in the Universe is hydrogen or helium. Stars convert these into heavier elements under the intense heat in their centers, eventually making up carbon, oxygen, iron, and many other elements. These are thrown out into space during supernova explosions, and eventually mix into the gas that forms new stars and planets. The iron in your blood, the calcium in your bones, and the oxygen you breathe was formed in exploding stars!

COMMON QUESTIONS OR MISCONCEPTIONS

- Don't be surprised if some students have never seen Orion or other well-known constellations. It is important to recognize that city lights can be bright enough to make it very difficult to see any but the brightest stars.
- The stars we see at night are not all at the same distance. Students often think of stars that make up the familiar constellations as being somehow physically connected. In fact, they are typically all at very different distances.
- Will the Sun ever explode? No, it does not have enough mass for this to happen.

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- Will the Sun last forever? No, it won't. It will eventually run out of fuel, but this will not happen for many billions of years.
- How does the Sun shine? The gravity of the Sun causes its gasses to compress toward the center. This compression causes the temperature to rise high enough to emit light. In fact, in the center the temperature is so high that nuclear fusion occurs, turning hydrogen into helium and releasing a lot of energy.
- Could a supernova explosion affect the Earth? Yes, if it occurred within a distance of about 26 light-years. (A light-year is the distance light can travel in one year—about 10 trillion kilometers.) This could be close enough for the energy of the explosion to affect the Earth's ozone layer that protects us from harmful radiation. This may have actually happened earlier in the Earth's history. There are currently no massive stars this close to the Earth.
- Is astronomy the coolest, most amazing science there is? Yes, it is! Well, ok, actually most areas of science are cool and amazing—and quite a bit of fun too. One of the great things about astronomy is that we have records of people studying it for thousands of years. A cool summer evening spent staring up at the starry sky is enough to tell you why!

DEMONSTRATIONS AND ACTIVITIES

- **Little stars, Big stars.** Stars come in many different sizes. During the part of their lives where they are converting hydrogen to helium at their centers (which is the vast majority of their lives), their surface temperatures are directly related to their masses. Low-mass stars are cooler than high-mass stars. The color of a star is directly related to the temperature. Cool stars are red, hotter stars are yellow, and very hot stars are blue. There are many more low-mass stars than high mass stars (just as there are many more pebbles in a quarry than there are huge rocks). You can convey this picture by getting a bouquet of balloons. Get one very large blue one, a couple of medium-size yellow ones, and a larger number of small red ones. Interestingly, the biggest stars live the shortest lives; they burn themselves out very quickly, and go out with a bang. You can pop the blue one with a pin to demonstrate the explosion. For the others, yellow first followed by red, you can slowly let the air out, letting them gracefully collapse to their final states. (Note: One confusing thing is that as massive stars evolve beyond the hydrogen-fusion stage, their outer layers expand and cool, turning red. Thus, while low-mass stars are red, one can also have “red supergiants” like Betelgeuse, which are actually very massive stars at a different stage of evolution.)
- **Core collapse.** The result of losing the pressure support at the center of a star, and having the heavy atmosphere of the star crush the core, can be demonstrated with a soda can, a Bunsen burner, and a bowl of ice water. Point out to the students that the Earth's atmosphere is very heavy, and is pushing down on the can. Lucky for the can, there is also air inside pushing back out, providing a pressure support against gravity's pull on the atmosphere.

What happens when you remove that air? Place about 1/8th of an inch of water in the can and hold it over the Bunsen burner until it is boiling vigorously. Use tongs to hold the can, and wear safety

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glasses. The steam heats the air in the can and pushes much of it out. Once there is a steady amount of steam coming out of the can, quickly turn it upside down and dunk it into the bowl of ice water. The rapid cooling of the little air that remains in the can decreases its pressure, and the can is quickly crushed by the atmosphere. This is what happens to the center of a star during a supernova explosion. (Note: The can gets very hot. Wear oven mitts when holding the tongs. It is important to turn the can upside down and put it in the cold water quickly; otherwise the water will have a chance to flow back into the can to equalize the pressure, and the can won't collapse. It is best to use a clear bowl for the ice water so that the students can see exactly what is being done. The can will not significantly change the temperature of the ice water, but care should be taken if using a glass bowl simply to ensure that it is not knocked over during the demonstration.)

- **Core bounce.** You can demonstrate the ejection of the outer layers of a star in a supernova explosion using a basketball and a tennis ball. Place the tennis ball on top of the basketball and then drop them. When the basketball hits the ground, it compresses and then bounces back up. This transfers a lot of momentum to the tennis ball, and it will fly high in the air. (Note: It can be a bit tricky to balance these so that the tennis ball doesn't fly off sideways. Practice makes perfect! Also, replacing the tennis ball with a ping-pong ball or a compact "super" ball—a hard rubber ball that bounces very well by itself—works even better.)
- **Star gazing.** Encourage the students to go outside with parents and friends on a clear, dark night. Have them choose a spot where they can see lots of stars. There are numerous things that can be observed, depending in part on location and how dark and clear the skies are. Encourage interaction between the observers; this is best done in groups. Who can spot the brightest star? How about the faintest? Are different stars different colors? Do some "twinkle" more than others? If so, are they high in the sky, or close to the horizon? Don't be surprised if someone spots a "star" that is moving slowly across the sky. This could be a plane, though that should become obvious after a while (the light may get brighter as the plane approaches, or the lights may blink), but it may also be a satellite in orbit high above the Earth, reflecting light from the Sun (though it has already set)!

RESOURCES

<http://www.nctm.org/>

IMSEnet is brought to you by the SERVIT Group, Department of Mathematics, Science, and Technology Education, North Carolina State University. Although this site is old, last updated in 2001, it provides a vast array of links to excellent sites that are still active.

<http://www.nasa.gov/>

NASA's mission is to pioneer the future in space exploration, scientific discovery and aeronautics research. To do that, thousands of people have been working around the world—and off of it—for 50 years, trying to answer some basic questions. What's out there in space? How do we get there? What will we find? What can we learn there, or learn just by trying to get there, that will make life better here on Earth?

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<http://nasascience.nasa.gov/educators/space-science-explorers>

Space Science Explorers - Who are NASA's Space Science Explorers? The scientist studying black holes in distant galaxies. And the engineer designing robotic instruments that will probe hard-to-reach planets. But also the teacher explaining the mysteries of the cosmos to his or her students. And the elementary school student wondering if life exists anywhere besides Earth. All of these people are Space Science Explorers—they are all connected by their quest to explore and understand our solar system and universe. This monthly series will introduce you to NASA Space Science Explorers, young and old, with a variety of backgrounds and interests.

<http://search.nasa.gov/search/edFilterSearch.jsp?empty=true>

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