SUPERNOVA EDUCATOR GUIDE

The Story of the Life of a Supernova

National Aeronautics and
Space Administration

http://glast.sonoma.edu ***http://xmm.sonoma.edu***

Content

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About this Guide

Busy educators sometimes have trouble finding ways to help their students feel the excitement of science in action. As a part of its educational effort, the NASA Education and Public Outreach group at Sonoma State University has put together an educational guide based on the science of one of NASA's Gamma-ray Large Area Space Telescope (GLAST) and the joint ESA/NASA XMM-Newton Observatory. The science specifically detailed in this guide covers the life cycle of a supernova.

Since students remember and understand better when they actively engage in manipulating the concepts about which they are learning, we have included several hands-on activities to help keep their interest and reinforce their comprehension and retention of the scientific concepts behind the current observations of the XMM-Newton mission and the future observations of the GLAST mission. We have also included information about both missions, what kind of objects they will observe, and why astronomers are interested in them. To help you determine when this project might be of most use to you in your science and/or math curriculum, we have included in the following pages a list of all of the national math and science standards covered.

What will my students learn from these activities? This series of activities uses supernovae – distant explosions from dying stars – as an engagement to teach basic concepts in physical science and mathematics. Below is a summary of all of the activities in this guide.

Summary of Activities

Activity 1 - Biography of a Supernova

Brief overview:

Students will write an essay describing the evolution of a supernova remnant based on pictures from the Supernova Poster.

Science Concepts

- Astronomical objects change over time
- The change in some astronomical objects can be observed and measured

Duration: ½ - 2 hours (can be done as homework or in class)

Essential Question: What are the stages in the evolution of a supernova remnant?

Grades: 7 – 12

Activity 2 – Crawl of the Crab

Brief overview:

Students use two images of a supernova remnant separated in time by several decades to determine the expansion rate of the glowing gas.

Science Concepts

- Astronomical objects change over time
- The change in some astronomical objects can be observed and measured
- The expansion of a supernova remnant can be used to determine its age

Duration: 1 hour

Essential Question: How can the date of a supernova explosion be determined using images of the expanding remnant?

Grades: 8 – 12

Activity 3 – At the Heart of a Supernova Explosion

Brief overview:

Students investigate the magnetic fields and other properties of pulsars and compare them to the Earth's magnetic field.

Science Concepts:

- Neutron stars/pulsars are complex natural phenomena that combine large gravity effects with magnetic fields.
- Rotating astronomical objects, like pulsars and the Earth, have magnetic fields.
- A neutron star is the dense stellar core remaining after a supernova explosion.
- A pulsar, a spinning neutron star, has jets of light and moving particles.

Duration: 1-3 hours

Essential Questions:

What is a neutron star?

What is a pulsar?

What are the similarities and differences between the magnetic field of a pulsar and that of the Earth?

Grades: 8 – 12

National Science Education Standards – Grades 9-12

	Activity 1 **Biography of a Supernova**	**Activity 2** **The Crawl of the Crab**	**Activity 3** **The Heart of a Supernova Explosion**
Science as Inquiry	• Abilities necessary to do scientific inquiry - *Identifying questions and concepts* - *Use of technology and mathematics to improve…* • Understanding about scientific inquiry	• Abilities necessary to do scientific inquiry - *Use of technology and mathematics to improve, invest, and communicate* - *Recognize and analyze alternative explanations and models* • Understanding about scientific inquiry	• Abilities necessary to do scientific inquiry - *Identifying questions* - *Design and conduct investigations* - *Formulate and revise scientific explanations* • Understanding about scientific inquiry
Physical Science		• Conservation of energy and increase in disorder	• Motion of forces • Interactions of energy and matter
Earth and Space Science	• Origin and evolution of the universe	• Origin and evolution of the universe	
Science and Technology	• Understanding about science and technology		• Abilities of technological design - *Implement a proposed solution* - *Evaluate the solution and its consequences* - *Communicate the problem, process, and solution* • Understanding about scientific inquiry
History and Nature of Science	• Science as a human endeavor • Nature of science knowledge	• Science as a human endeavor • Nature of science knowledge	• Science as a human endeavor • Nature of science knowledge

Mathematics Standards for Supernova Activities

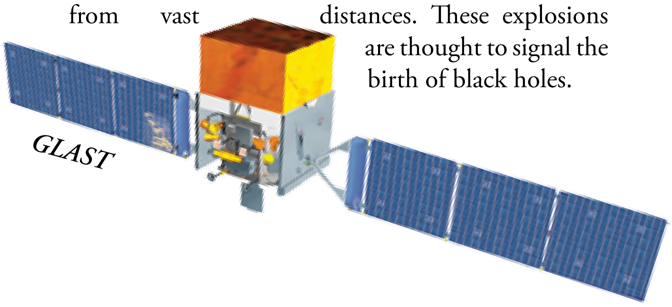
Activity 1 - Biography of a Supernova: No math standards for this activity.

	Activity 2 The Crawl of the Crab	Activity 3 The Heart of a Supernova Explosion
Algebra	• Understand patterns, relations, and functions • Represent and analyze mathematical situations and structures using algebraic symbols • Use mathematical models to represent and understand quantitative relationships	• Understand patterns, relations, and functions • Represent and analyze mathematical situations and structures using algebraic symbols • Use mathematical models to represent and understand quantitative relationships
Geometry	• Specify locations and describe spatial relationships using coordinate geometry and other representational systems • Use visualization, spatial reasoning, and geometric modeling to solve problems	• Specify locations and describe spatial relationships using coordinate geometry and other representational systems • Use visualization, spatial reasoning, and geometric modeling to solve problems
Measurement	• Understand measurable attributes of objects and the units, systems, and processes of measurement • Apply appropriate techniques, tools, and formulas to determine measurements	• Understand measurable attributes of objects and the units, systems, and processes of measurement • Apply appropriate techniques, tools, and formulas to determine measurements
Data Analysis and Probability	• Formulate questions that can be addressed with data and collect, organize, and display relevant data to answer them • Select and use appropriate statistical methods to analyze data • Develop and evaluate inferences and predictions that are based on data	• Develop and evaluate inferences and predictions that are based on data
Communication	• Organize and consolidate their mathematical thinking through communication • Communicate their mathematical thinking coherently and clearly to peers, teachers, and others	• Organize and consolidate their mathematical thinking through communication • Communicate their mathematical thinking coherently and clearly to peers, teachers, and others
Connections	• Recognize and use connections among mathematical ideas • Recognize and apply mathematics in contexts outside of mathematics	• Recognize and use connections among mathematical ideas • Recognize and apply mathematics in contexts outside of mathematics
Representation	• Create and use representations to organize, record, and communicate mathematical ideas • Select, apply, and translate among mathematical representations to solve problems • Use representations to model and interpret physical, social, and mathematical phenomena	• Create and use representations to organize, record, and communicate mathematical ideas • Select, apply, and translate among mathematical representations to solve problems • Use representations to model and interpret physical, social, and mathematical phenomena

What is the Gamma-ray Large Area Space Telescope (GLAST)?

The Gamma-ray Large Area Space Telescope (GLAST) is a NASA satellite planned for launch in 2007. GLAST is part of NASA's Science Mission Directorate. Astronomical satellites like GLAST are designed to explore the structure of the Universe, examine its cycles of matter and energy, and peer into the ultimate limits of gravity: **black holes**. GLAST is being built in collaboration between NASA, the U.S. Department of Energy, France, Germany, Italy, Japan, and Sweden. The project is managed from NASA's Goddard Space Flight Center in Greenbelt, Maryland. GLAST detects **gamma rays**, the highest energy light in the electromagnetic spectrum.

There are two scientific instruments on board GLAST: the Large Area Telescope (LAT) and the GLAST Burst Monitor (GBM). The LAT is the primary instrument, and will survey the sky in high-energy gamma-ray light. It will also study many individual sources of gamma rays. The GBM will detect Gamma Ray Bursts, tremendous explosions coming from vast distances. These explosions are thought to signal the birth of black holes.

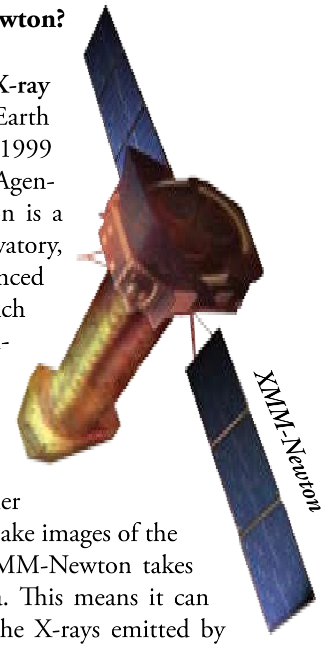


Who developed these activities?

The activities have been developed as part of the NASA Education and Public Outreach (E/PO) Program at Sonoma State University, under the direction of Professor Lynn Cominsky.

Contributors to this education unit include Professor Lynn Cominsky, Dr. Kevin McLin, Dr. Philip Plait, Sarah Silva, and Aurore Simonnet. We would also like to acknowledge input from lots of other nice people too.

What is XMM-Newton?



XMM-Newton is an **X-ray** satellite launched into Earth orbit on December 10, 1999 by the European Space Agency (ESA). XMM-Newton is a fully-functioning observatory, carrying three very advanced X-ray telescopes. They each contain 58 high-precision concentric mirrors, nested to offer the largest collecting area possible to catch X-rays. Unlike many other telescopes, which only make images of the objects they observe, XMM-Newton takes both images and spectra. This means it can measure the energy of the X-rays emitted by an astronomical object, which allows scientists to determine many of its physical characteristics including temperature, composition, and density.

XMM-Newton was initially called just "XMM", which stands for "X-ray Multi-Mirror" due to the design of the mirrors. To honor one of history's most famous scientists, ESA attached the name of Isaac Newton to the XMM mission.

XMM-Newton can obtain spectra of far fainter objects than any previous spectroscopic X-ray mission because its mirrors have more collection area than those on any previous mission. The detectors onboard XMM-Newton are also very sensitive, allowing faint objects to be observed. A third advantage is that it has an unusual **orbit** that takes it out to nearly one third of the distance to the Moon. This highly elliptical orbit means that XMM-Newton can make long, uninterrupted observations, giving it the time it needs to see fainter astronomical objects.

Where can I get more information?

Appendix B of this booklet contains a list of resources for XMM-Newton and supernovae.

To learn more about GLAST, and XMM-Newton education and public outreach, visit:

http://glast.sonoma.edu or http://xmm.sonoma.edu

INTRODUCTION TO SUPERNOVAE

According to the Annals of the Sung Dynasty (the Sung-shih), on the first day of the chi-ho reign period, during the 5th month, on the chi-chou, a "guest star" appeared to the south east of Tian-kuan. The guest star was so bright that it could be seen during the daytime, and it remained so for 23 days. After that, it gradually dimmed, finally fading from visibility after two years. Japanese records also mention the star.

An unknown artist may have recreated the appearance of the Crab Nebula supernova in 1054 on the side of a cave wall in Chaco Canyon, New Mexico.

At around the same time, half a world away from China in what we now call Chaco Canyon, in Northern New Mexico, an ancestor of today's Hopi and Navajo painted what appears to be a "guest star" into a protected rock overhang. The star is shown next to the crescent moon, and a hand print, perhaps that of the artist, is also painted on the rock. Though this record is not as detailed as that of the Sung astronomers, the orientation of the moon and the guest star is what it would have been on that day when the Sung reported their guest star, strongly suggesting that the two are the same.

Such an impressive object, recorded in disparate cultures around the globe, must have been visible in Europe as well as Asia and North America. However, the date given in the Chinese annals, by our modern reckoning, would have been July 4, 1054. At that time Europeans were in the throes of the Dark Ages, and the Norman Invasion was just a few years away. Perhaps they were too occupied with worldly concerns to mark down the appearance of a celestial visitor, or perhaps whatever record existed has been lost. In any case, no European record of the event has ever been found.

Since the appearance nearly a millennium ago of the Sung "guest star" there have been only two other similar objects seen in our **Galaxy**. One occurred in 1572 in the constellation Cassiopeia. This was observed by the Danish astronomer Tycho Brahe and bears his name. It became bright enough to be visible in full daylight. The other star appeared in the constellation Ophiuchus in 1604 and was studied by Tycho's student and collaborator, Johannes Kepler, though it was seen earlier by several other people. Kepler's star, while not as bright as Tycho's, was still as bright as Jupiter. Since the appearance of Kepler's star, no others have been seen in the Galaxy.

This does not mean, however, that no additional similar objects have been observed. In 1885 a new star appeared in the center of the Milky Way's companion galaxy M31, in the constellation of Andromeda. It reached a peak brightness of 6-7th **magnitude**, making it easily visible in small telescopes against the background glow of the galaxy itself. The object is important for historical reasons because it was used to argue, incorrectly, that the great spiral nebula of Andromeda was a new star system, like our **solar system**, in the process of forming within our own galaxy. The astronomer Harlow Shapley, in a famous 1922 debate with Heber Curtis on the nature of the spiral nebulae, claimed that the appearance of the guest star in Andromeda was due to a "new sun" just beginning to turn on. His argument was later shown to be wrong. Edwin Hubble measured the distance to the Andromeda nebula and proved it was extremely far away and, in fact, an independent system of stars – a galaxy on a par with our own Milky Way.

Though these guest stars are rare events in any given galaxy, the universe contains many, many galaxies. With the advent of large telescopes in the 1920s and 30s it was soon noticed that guest stars could be seen quite often if one looked at many galaxies. The fact that the guest stars were nearly as bright as the galaxies in which they occurred meant that they were enormously energetic. Their great brightness and release of energy prompted the astronomer Fritz Zwicky to dub them **supernovae** because they appeared similar to, but far brighter than, the "novae" seen in our galaxy. Supernova is the name by which we still call them today, though we now know they have nothing in common with novae except a name: supernovae are exploding stars, whereas novae are the much smaller explosion of the atmosphere of a **white dwarf** star that is acquiring matter from a nearby binary companion star. *(For more about the supernova life cycle, see p.8.)*

In an ironic twist, recent observations of supernovae similar to the one seen in Andromeda in 1885 have allowed us to measure the vast size and expansion rate of the universe. To our great surprise, these extremely distant supernovae indicate that the expansion is accelerating, rather than slowing down. These observations indicate that approximately 70% of the energy in the universe is something never before observed, with properties heretofore only imagined in the most speculative of our theories of nature. Far from showing that the universe is small, as Shapley argued, supernovae have shown us that the universe is not only vast, but much stranger than we had imagined.

The Crab Nebula is located just above the star marking the tip of the lower horn of Taurus, the Bull.

If you point a telescope toward the patch of sky described in the Chinese records from 1054, just a few degrees north and east of Aldebaran, the "eye" of Taurus, the bull, you will find a faintly glowing cloud. This is the Crab Nebula. It is the remains of a star that exploded some 7000 years ago. The explosion was seen on Earth only 1000 years ago because it was so distant that its light required 6000 years to reach us; the Sung and Chaco Canyon inhabitants were seeing the explosion 6000 years after it happened. The Crab Nebula is a **supernova remnant**, the debris from an exploded star. It is still expanding today at more than 1000 km/s, (for more about supernova expansion see p.11) having slowed from an initial expansion speed of more than 10,000 km/s. Inside the nebula is the Crab pulsar, the compact remnant of the core of the exploded star. The pulsar is a highly magnetized, rapidly spinning **neutron star**, a class of object that is among the most bizarre found in nature. A mere teaspoon of the crab pulsar would weigh more than a billion tons (for more about neutron stars see p.22.)

In the remainder of this education unit, you will explore the amazing properties of supernovae and neutron stars. You will also begin to learn about some of the tools scientists use to understand them.

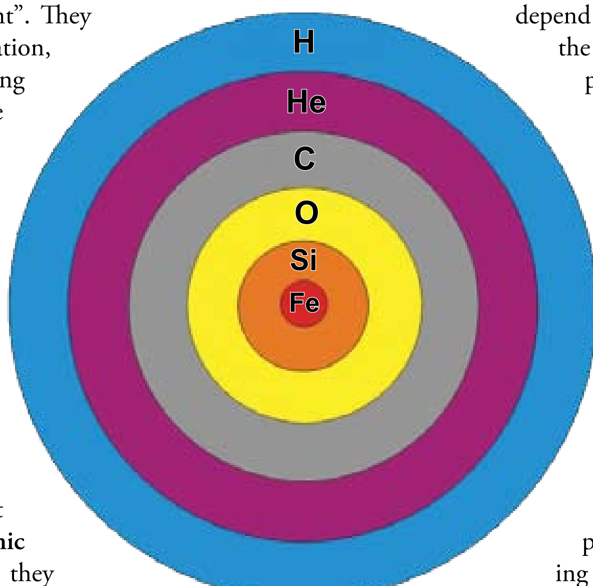
Why Stars Explode

The stars in the sky seem eternal and unchanging.

But that's an illusion. Like all things, stars are born, live out their lives, and eventually die, doomed to fade away. Stars like the Sun, which have a relatively low mass, age gracefully and die quietly after billions of years. But massive stars, with more than ten or so times the mass of the Sun, "do not go gently into that good night, but instead rage, rage against the dying of the light". They explode in a catastrophic detonation, sending their outer layers screaming outwards at a few percent of the speed of light: what astronomers call a supernova.

The seeds of a star's ultimate destruction are planted deep in its core, where its energy is generated. Stars are giant balls of gas, and when a gas is compressed it heats up. Because stars are so big they have a lot of gravity, so at the core of a star the pressure is intense. This means they get very hot, hot enough to smash together **atomic nuclei**. And when nuclei collide, they can stick together in a process called fusion. This process releases a lot of energy (in fact, it's what makes hydrogen bombs explode), which heats up the core. In a stable star like the Sun, the inward crush of gravity is balanced by outward pressure caused by the heat. Already we see that the mass of the star is important: it provides the gravity needed to compress the core. The higher the mass of the star, the more the core is compressed, and the hotter it can get. Fusion reactions depend strongly on temperature; the higher the temperature, the faster the reaction proceeds. As we'll see, this is critical later in the star's life.

Initially, the star fuses hydrogen into helium. Like ash in a fire, the helium builds up in the core, but it does not fuse because helium takes a lot more pressure and heat than hydrogen does to fuse. If the star is massive enough, though, it can ignite helium fusion in its core. The helium fuses into carbon, which then starts to pile up in the core. In very massive stars this process repeats again and again, fusing lighter elements into heavier ones: hydrogen to helium, helium to carbon, carbon to neon, neon to oxygen, oxygen to silicon, silicon to iron. The star's core starts to look like an onion, with layers nested inside one another.



Near the end of a massive star's life, the fusion occurs in shells around the core, like the layers of an onion.

At every step, the process generates more heat, and the fusion goes ever faster. A star may fuse hydrogen into helium for millions or billions of years, but by the time it starts to fuse silicon into iron, it may take mere days. As iron piles up in the core, the star is headed for disaster.

Why? Because up until iron, all the fusion reactions have produced energy in the form of heat. That heat holds the star up. However, iron is different. It takes energy to fuse iron into heavier elements, and this energy must come from the star itself. When enough iron builds up in the core, the pressure becomes great enough that it starts to fuse. This robs energy from the star, cooling it. Worse, the fusion of iron eats up copious amounts of **electrons**, and the motion of these electrons was helping to hold up the star too.

These pictures shows the location of Supernova 1987a before it exploded (left), and during the explosion (right)

When iron starts to fuse, things go bad fast. The iron core collapses, since the heat and electrons holding it up get used to fuse the iron. In a thousandth of a second the tremendous gravity of the core collapses it down from thousands of kilometers across to a ball of compressed matter just a few kilometers in diameter. This is a bit like kicking the legs out from under a table. Just like when Wile E. Coyote suddenly realizes he is no longer over solid ground and starts to fall, the outer layers of the star come rushing down. They slam into the compressed core at a significant fraction of the speed of light.

This does two things: it sets up a huge rebound, sending the outer layers of the star back out, and also releases a vast number of neutrinos, subatomic particles that carry away most of the energy of the collapse. The gas from the outer layers absorbs only a small fraction of these neutrinos, but that's still a lot of energy: it's like lighting a match in a fireworks factory. The outer layers of the star explode upwards, and several **solar masses** of doomed star (containing the elements that were produced before the explosion) tear outwards at speeds of many thousands of kilometers per second.

The Elephant Trunk Nebula
David De Martin (http://www.skyfactory.org), Digitized Sky Survey.

As the star explodes, the expanding gas is so hot that it can undergo temporary fusion, creating elements as heavy as uranium. This, plus other **radioactive** elements created in the explosion, dumps even more energy into the gas, causing it to glow. The expanding gas is called a supernova remnant; it will expand for hundreds of thousands of years, eventually cooling and becoming so thin it merges with the tenuous gas between the stars. Sometimes the gas from the remnant will hit and mix with gas that is forming new stars, seeding it with the heavy elements formed in the explosion. The iron in your blood and the calcium in your bones were formed in the supernova explosion of a massive star millions of years before the formation of the Earth itself.

And what of the core? Like the life of the star itself, the fate of the core depends on its mass. In relatively low-mass stars like the Sun, the star never explodes at all. The core is not massive enough to fuse helium, so helium simply builds up. Or perhaps helium does fuse, but then the star is not massive enough to fuse the resulting carbon. In any event, the outer layers of the star are blown off by a solar wind over millions of years, and the naked core, unable to generate its own heat, simply cools and fades away. A star that consists of this revealed core is called a white dwarf.

If the core is more massive, between 1 and 3 times the Sun's mass then things are different. The pressure from the collapse slams electrons into protons, creating **neutrons**. The core shrinks to a size of a few kilometers across, and is comprised almost totally of these neutrons. The collapse is halted by the neutrons themselves, which resist the pressure. Not surprisingly, this object is called a neutron star.

And for more massive cores? Even the neutrons cannot resist the pressure created by more than about 3 times the Sun's mass when it collapses. The core implodes, and nothing can stop it. Its gravity increases hugely, and anything that gets too close will be drawn in, even light. It has become a black hole.

This is more than just theory. By studying supernovae, supernova remnants, and other exotic objects, astronomers have discovered all this and much more. If you want to continue reading about this and get more information, check out the Resources list in Appendix B.

1

Biography of a Supernova

Duration:
1 hour or multiple days

Essential Question:
What are the stages in the evolution of a supernova?

Objectives

Students will:

- be able to describe in general terms the various stages of a supernova as it ages
- see that astronomical objects change over time
- understand where the elements are created

Science Concepts:

- Astronomical objects change over time
- The change in some astronomical objects can be observed and measured

Background Information

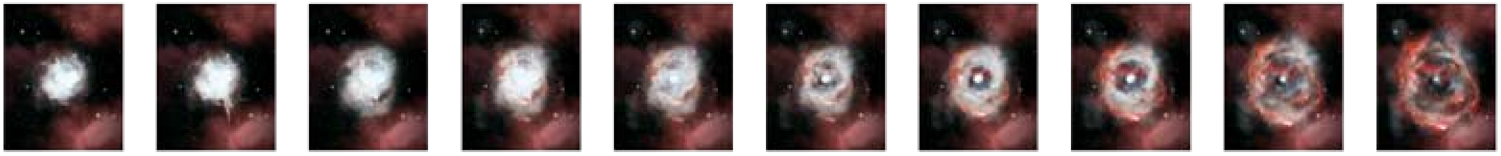
When the supernova blast wave breaks through the surface of the doomed star, it sets into motion a series of events and processes which will literally shape the fate of the expanding gas over the ensuing millennia.

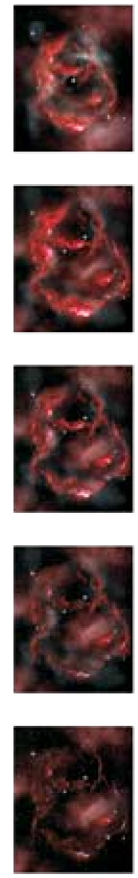
The outer layers of the star explode outward due to the blast wave created when the core of the star collapses. The heat and pressure from this blast are so high that nuclear fusion can actually take place in the material. Elements up to uranium on the periodic table are created, many of which are radioactive. Isotopes of cobalt, aluminum, titanium, and nickel are all produced in the fireball. Expanding gas normally cools, but as these radioactive elements decay they produce high-energy gamma rays. The gas absorbs this radiation, heating it. After a week or two, much of the light emitted by the supernova remnant is due to this heating from radioactive decay.

As time goes on, the remnant continues to expand. During the first stage of its life, the gas in the remnant is dense enough that it is opaque; we only see the outer part of the expanding cloud. But as it expands its volume increases, so its average density drops. Eventually, like a fog clearing, the gas becomes transparent to visible light. We see deeper into the remnant, and after a few years the spinning pulsar — the collapsed core of the star — becomes visible (if it exists). (Note: Scientists have not located a neutron star at the center of every supernova remnant.) The gas inside the remnant is energized by the magnetic fields of the pulsar (see activity 3). That gas is diffuse and glows with a bluish hue. The gas in the outer parts of the remnant, however, has been compressed into thin filaments and ribbons by the shock wave, and is dominated by emission at discrete wavelengths. This gas glows mostly red and green.

Over many thousands of years, the pulsar-energized gas from the inner part of the nebula has caught up with and merged with the outer gas. The pulsar spin has slowed, its energy given to the expanding remnant. All that's visible now are the shocked filaments, thin wisps of gas. The remnant resembles a giant spider web.

Eventually, over tens or even hundreds of thousands of years, the gas in the remnant mingles with the gas between the stars in the Galaxy. The remnant is no longer a discrete entity, but instead has merged with the **interstellar medium**. A cloud of gas and dust hit by the expanding remnant gets compressed as they collide, causing it to collapse. If it's compressed enough, its own gravity can accelerate that collapse. The core of the cloud becomes dense and hot, and new stars can form there. These stars may have their element content enriched by the supernova: heavy elements such as calcium, silicon, uranium, iron, and many others seed the newly-forming stars. These heavy elements are necessary to form planets, and in fact the iron in our blood and the calcium in our bones were formed in the heat and fury of some ancient supernova. We owe our very existence to some long-dead star, whose remains deposited its contents into the cloud of gas and dust that eventually became the Sun, the Earth… and us.





Begin

End

Procedure:

> **Materials**
> • Supernova Poster

1) In class: Show students the supernova poster. Specifically, point out the "Supernova Timeline," the series of pictures running along the bottom of the poster, and reproduced here, around the top of the page. This timeline shows the evolution of a supernova remnant from the explosion itself to when the gas starts to fade and mix with the interstellar material in the Galaxy. On the back of the poster (and included above in the "Background Material" section) is a description of the events for the timeline. If you wish, you can make copies of the description for the students, and you can read it aloud as the students follow along, or you can simply have them read it in class.

2) Homework: Have the students write a one page "Biography of a Supernova" describing the events in the timeline as seen up close. Let them use their imagination: they can be technical and matter-of-fact, or they can write it like a story with events seen from a nearby spaceship, or they could even write it first person as if they are the supernova. They can look up information they need on the internet if needed (some helpful links are provided in Appendix B, and in the "Additional Information" section p.10) or they can use the activities in this Educator Guide.

3) Post-class: Choose one or two of the essays and have the students read them aloud to the rest of the class. They can vote on the favorite, or which one they thought was most entertaining and/or most accurate. Again, let them use their imaginations.

Assessment:

Points	Diagnostics
4	Essay is complete, accurate, imaginative, and turned in on time
3	Essay is mostly correct and complete, and turned in on time
2	Essay is somewhat accurate and complete, turned in late
1	Essay is incorrect and incomplete, turned in late
0	Nothing turned in

Answer Key:

There is no official answer key for this exercise. The goal is for the students to use their imagination, research the essay, and have fun.

BIOGRAPHY OF A SUPERNOVA - 1

Additional Information

Some useful websites for students to provide more information on their essay:

1. **Astronomy Notes: The Lives and Deaths of Stars:**
   http://www.astronomynotes.com/evolutn/chindex.htm
2. **Bad Astronomy: The History of Supernova 1987A:**
   http://www.badastronomy.com/bitesize/sn87a_discovery.html
   http://www.badastronomy.com/bitesize/sn87a_timeline.html
3. **Imagine the Universe! Stellar Evolution and Supernovae:**
   http://imagine.gsfc.nasa.gov/docs/science/know_l2/stars.html
   http://imagine.gsfc.nasa.gov/docs/science/know_l2/supernovae.html
4. **NASA's Observatorium: Stellar Death:**
   http://observe.arc.nasa.gov/nasa/space/stellardeath/stellardeath_3.html
5. **The Lives and Deaths of Stars (for advanced students):**
   http://brahms.phy.vanderbilt.edu/%7erknop/classes/a102/fall2003/handouts/stlrev.pdf
6. **Wikipedia entry for stellar evolution:**
   http://en.wikipedia.org/wiki/Stellar_evolution

THE CRAWL OF THE CRAB

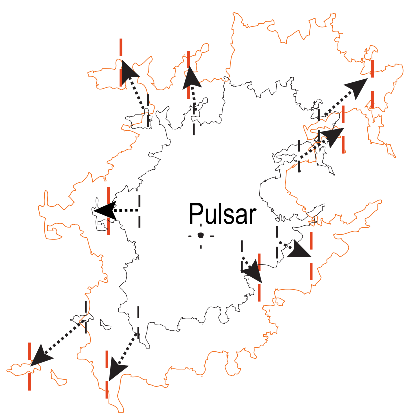
2

Duration:
1 hour

Background Information

A supernova explosion generates a tremendous amount of energy. A tiny fraction of this energy goes into blowing the outer layers of the star outwards… but in a supernova event, even a tiny fraction can mean a lot of energy!

When a massive star explodes, its outer layers are ejected at speeds of thousands of kilometers per second. The total mass of the gas ejected can be ten or more times the mass of the Sun! As the shock wave from the explosion rips through the star, the gas forms long filaments and relatively small clumps called **knots**. These formations can be observed for a long time, even centuries after the explosion. If you could trace the motion backwards in time, you would see they all come from a central point, where the star originally exploded (see figure below). Many times, that location is marked by the collapsed core of the star, the part that didn't explode outwards. This collapsed "cinder" of the explosion may be a black hole or a fantastically dense and rapidly spinning "pulsar." Pulsars are so-named because to us here on Earth they appear to flash on and off as beams of emission sweep past us, like the beams of light from a lighthouse (see Activity 3, "The Heartbeat of the Supernova", for more information).



As the gas in the Crab expands, it moves away from the central pulsar. The expansion depicted here is exaggerated, and is not to scale.

The expanding gas moving away from the central object is called the "supernova remnant" (SNR), or sometimes generically as a nebula (which is Latin for "cloud"). Images of these SNRs show them to be quite lovely, glowing in different colors, strewn with filaments and knots. But besides their other-worldly beauty, they also reveal interesting and important information about the supernova event itself.

Some of this information can be deduced simply by examining images. SNRs have been a favorite target of astrophotographers for decades, and one in particular is a favorite: the Crab Nebula (usually just called the Crab). It's relatively bright, making it easy to photograph, and is up high in the sky for many northern observers. Located in the constellation of Taurus the bull, it's even visible by binoculars in the winter months in the northern hemisphere and much of the southern hemisphere.

At first glance, images of the Crab Nebula taken at different times look pretty much the same. Sure, more recent images may look better due to advances in imaging, telescopes, and processing of pictures. But there are also differences in the images which are intrinsic to the Crab itself, changes due to physical changes in the nebula.

Most people think of astronomical objects as being static, unchanging. But remember, the gas in the Crab is expanding at thousands of kilometers per second! Its vast distance (6000 **light years** or so) shrinks this motion to an apparent crawl, but over time, the expansion will make itself known.

Overview

In this activity, your students will compare two images of the Crab Nebula taken more than 40 years apart. By measuring the motion of some of the knots of glowing gas they'll be able to determine the date of the supernova explosion that set the Crab into motion.

The idea is relatively simple. Between the times of the two images, the Crab has expanded. The students will measure the distance between a series of knots and the central point of the explosion, marked now by the presence of a pulsar. The difference between the two measurements is due to the expansion of the gas during the time interval between the images. Since that distance can be measured, and the time interval is known, the expansion rate can be determined. Since rate = distance / time, and the rate and distance are known, the amount of time the knots have been expanding can be calculated. In other words, by measuring the differences between the images, the age of the nebula (and hence its "birthday") can be found.

Essential Question:

How can the date of a supernova explosion be determined using images of the expanding remnant?

Objectives:
Students will…

- be able to use a ruler to measure distances and use correct numbers of significant digits
- see that astronomical objects change over time
- plot data to observe trends
- examine data and make conclusions about data quality
- determine the year that the supernova occurred

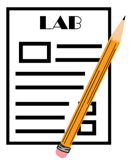
Science Concepts

- Astronomical objects change over time
- The change in some astronomical objects can be observed and measured
- The expansion of a supernova remnant can be used to determine its age

Additional Information:

Two versions of this activity are available. In one version, the student will analyze digital images on their computer screen using freely available imaging software and an Excel spreadsheet. You can find this version on the CD under the filename ***SN_Activity2_onscreen.pdf***. More detailed instructions are in that write-up. The other version of this activity is done via handouts.

The digital version involves measuring the coordinates of the pulsar and knots in the nebula, and using the distance formula to get the expansion amounts. This can be done by hand, or the students can use a pre-programmed Excel spreadsheet. The level of math involved is therefore under the teacher's control. The student can calculate averages, medians, and standard deviations of the ages found, again by hand or using the spreadsheet. This version is available on the enclosed CD in the folder "crawl-crab". The version using hardcopies of the images is below.



In the printed version the students measure the distances of knots from the pulsar directly, so less formal math is needed. Testing has shown that measuring the knots is slightly faster using this method, but doing the math takes slightly longer. The printed version of this exercise is designed for teachers who do not have access to sufficient numbers of computers for their students, but other teachers may still choose to use it for pedagogical reasons.

Educator Tip: In both versions of the exercise, students will make a series of measurements. It is inevitable that some of the measurements will be less accurate than others. Encourage the students to examine their data and determine if any data points appear to be inaccurate. If they find any suspect measurements, they can re-measure the distances. Have a student who did not do the original measurement make the second measurements, so they are not biased. If they cannot improve the results, it is okay to throw out some data; this is what scientists do when they cannot make good measurements. Just make sure they have 8 or 9 data points that are good, or else their conclusions might be compromised.

Procedure:

Materials for each team of 2 or 3 students:

- Calculator
- Ruler
- Printed images of the Crab Nebula from 1956 and 1999 (supplied) p. 17-18
- Graph paper
- Student Handout p.15 and Worksheet p.19 (one per student, supplied below)

1) Pre-class: Read through the Background Information section, and go over the Student Handout and Worksheet. Students should work in teams of 2 or 3, so print out enough Handouts and Worksheets for the students. Each team also needs a copy of both Crab Nebula images (1956 and 1999). You should make the printouts using the original image: don't just make one printout and then photocopy it; the contrast will be too low to see details. Make sure that the pulsar, labeled stars, and labeled knots are visible. If the knots cannot be seen well, change the contrast on the image or the printer. If you are still having trouble, use an imaging display program (such as Photoshop or GIMP– see the computer-based version of this exercise for more information) to change the contrast.

2) In class: With the students, go over information about supernova remnants provided in the Background Information section. Tell them that by simply measuring the changes between two images, they will be able to determine the age of an astronomical object. Go over any vocabulary (such as "**arcsecond**," "knot," "**plate scale**," etc.). Before they start to make their measurements, stress that not all the knots are easy to measure, so they should be careful, and they should also pay particular attention to any tips given in the exercise.

3) Post-class: With the class, go over the students' results, and compare them to the "true" age of the Crab. How many students were close, how many were way off? Discuss possible places where errors could creep in, including general methods used or particular knots which may have caused problems. Tell them that methods such as the ones they used are also utilized by real scientists to find the ages of many astronomical objects.

Lesson Adaptations:
Measuring the knots involves some visual acuity. Students who are visually impaired can record the measurements instead of making them.

Assessment:

Points	Diagnostics
4	Answers and calculations are complete and correct, measurements are accurate and complete
3	Answers and calculations are mostly correct and complete, measurements are mostly accurate (good enough to get sufficiently correct analysis) and complete
2	Answers and calculations are somewhat correct and complete, measurements are incomplete, and inaccurate enough to adversely affect the analysis
1	Answers and calculations are incorrect and incomplete, measurements are inaccurate and incomplete
0	Nothing turned in

Answer Key - "The Crawl of the Crab"

Note: these answers were based on printouts of the images, which may vary from printer to printer. You should perform the exercise yourself on your own printouts, and check the student answers against your own. Use the answers below as a guideline, not as a hard-and-fast answer sheet.

1

Star Pair	Distance (cm)		Plate Scale (arcsec/cm)	
	1956	*1999*	*1956*	*1999*
A1 – A2	14.13	14.28	20.03	19.82
B1 – B2	17.90	18.12	20.22	19.98
C1 – C2	13.75	13.91	20.22	19.99
		AVERAGE:	20.16	19.99

2

knot	Distance from Pulsar (cm)	
	1956	*1999*
1	7.35	7.80
2	5.12	5.40
3	3.01	3.20
4	5.42	5.80
5	4.02	4.30
6	1.80	1.90
7	4.70	5.00
8	2.83	3.03
9	4.10	4.40
10	4.42	4.70
11	5.85	6.20

3

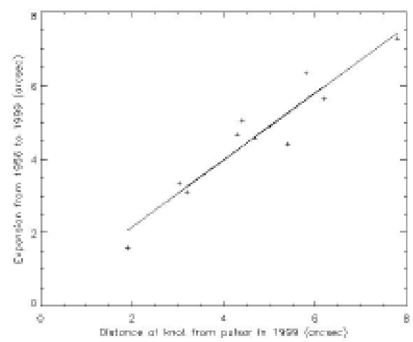
knot	Separation from Pulsar (arcseconds)	
	1956	*1999*
1	148.15	155.43
2	103.20	107.61
3	60.670	63.766
4	109.25	115.58
5	81.028	85.686
6	36.281	37.861
7	94.734	99.634
8	57.042	60.378
9	82.641	87.678
10	89.091	93.656
11	117.91	123.55

4

knot	Change in Separation from 1956 to 1999 (arcseconds)
1	7.28
2	4.41
3	3.10
4	6.33
5	4.66
6	1.58
7	4.90
8	3.34
9	5.04
10	4.57
11	5.63

a) The variation should be large, as the expansion speed of each knot is not correlated with any other knot.

b) Yes: the farther the knot is from the pulsar, the faster its expansion speed.



c) The expansion speed should increase linearly with distance from the pulsar (with some scatter due to measurement error). For an explosion, parts that move faster will move farther in a given time. So now, a thousand years later, the knots that are farther away will have a higher speed than those closer in.

5

Elapsed Time: 43.75 years

knot	Expansion rate (arcseconds/year)
1	0.166
2	0.101
3	0.708
4	0.145
5	0.106
6	0.036
7	0.112
8	0.076
9	0.115
10	0.104
11	0.129

6

Knot	Age of nebula (years)	Year of the explosion
1	934	1065 A.D.
2	1069	930
3	901	1098
4	799	1200
5	805	1194
6	1049	950
7	890	1109
8	792	1207
9	761	1238
10	897	1102
11	960	1039

Year of the explosion
MEDIAN: 1102
AVERAGE: 1103

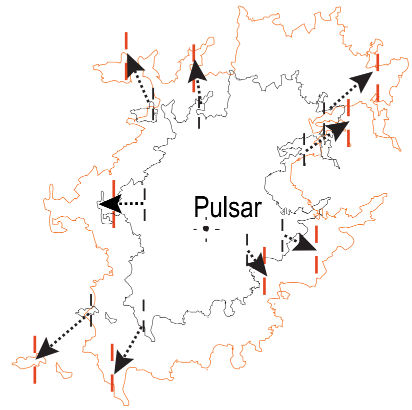
Age of nebula
MEDIAN: 897 years
AVERAGE: 896 years

STUDENT HANDOUT

THE CRAWL OF THE CRAB - 2

Introduction

Two images of the Crab Nebula supernova remnant, taken 46 years apart, clearly show the expansion of the gas due to the explosion. In this exercise, you will determine the age of the Crab by measuring how much it has expanded over that period of time. You will convert the amount of expansion to a rate of expansion, and from there work backwards to determine the year the star exploded to form the Crab Nebula. In a sense, you're trying to find the "birthday" of the Crab-- except this method isn't accurate enough to find the exact day, so really you're finding the birth *year* of the Crab.



As the gas in the Crab expands, it moves away from the central pulsar. The expansion depicted here is exaggerated, and is not to scale.

Procedure:

First, examine both images. They are presented in grey scale (what most people erroneously call "black and white"), and are reversed such that bright objects like stars are black, and dark objects like the background sky appear white. This is an old astronomer's trick to make faint detail easier to see. You can see that the gas is not smooth; there are filaments and knots of gas scattered throughout the nebula.

One image was taken in February 1956, and the other in November 1999. Both images look similar at first glance, but if you look carefully you'll see some differences. The images are not at the same scale; one is slightly magnified compared to the other (can you tell which is which?). The area of sky covered is slightly different as well. More subtly, the nebula itself has changed during the time interval between the two images. It is this change that you will measure, and from that determine when the Crab was born.

1 To measure the expansion of the gas, you first need to establish the scale of the images. This is similar to the scale of a road map, which for example might be given in kilometers/centimeter. In astronomical images this is measured in arcseconds/centimeter.

On each image, there are three pairs of labeled stars (A1 and A2, B1 and B2, C1 and C2). Using your ruler, measure the distance between the two stars in each pair in centimeters and record your results on the worksheet. Be as accurate as possible; 0.05 cm (0.5 mm) accuracy should be achievable, or better if you can.

The angular separations on the sky between the stars in each pair have been determined using star charts, and are listed below. Use these separations to determine the plate scale of the images in arcseconds/centimeter, and then calculate the average of your three numbers. Record your result in table 1.

Angular separation of stars

A1 and A2: 283 arcseconds
B1 and B2: 362 arcseconds
C1 and C2: 278 arcseconds

2 Near the center of the nebula is a star marked "**pulsar**". That is the collapsed core of the star that originally exploded. We can assume for this exercise that all the gas started at that star, so you will measure the expansion relative to the pulsar.

On both images, there are 11 knots of gas marked. Starting with the image from 1956, ***carefully*** measure the distance in centimeters (to the nearest 0.05 cm or better if you can) of each knot from the pulsar. Repeat these measurements for the 1999 image. Some of the knots are extended, or spread out a bit. For knots like that, pick an obvious feature to measure, like the center of the knot, or the edge on one side. Make sure you pick the same feature in both images! Otherwise your measurements will not be accurate. On the worksheet there is room for you to make short comments on what part of the knot you measured, which may help you if you need to go back and re-measure.

Tip: measure each knot in both images before going on to the next knot, rather than measuring all the knots in one image and then in the other. That way, you can be more consistent in the way you measure each knot. Another tip: it might help to measure the knots on the 1999 image first, since it has better resolution, and shows the structure of the knots more clearly. A third tip: sometimes measuring to the edge of a knot is easier than measuring to the center.

3 Using the average plate scale you derived in question 1, convert the distance you measured in centimeters in question 2 to angular separation in arcseconds (use unit analysis.)
Do you see any obvious trends in these numbers from one date to the other?

4 Now it's time to measure how much the nebula expanded: subtract the angular separation between each knot and the pulsar in 1999 from the angular separation in 1956.
a) Examine the numbers you just calculated. Are the expansion amounts all roughly the same (within, say, 10% of each other), or is there a large variation? Do you expect all the numbers to be about the same?

b) Now look at the amount of expansion for each knot compared to the distance of the knot from the pulsar. Do you see any trends?

c) To see if any trends exist, plot on your graph paper the expansion amount for each knot versus its distance from the pulsar in the 1999 image. Using your ruler, draw in a best-fit line to the points. Can you make any general statements about a relationship between the distance from the pulsar for a given knot and its speed of expansion? Try to think of a physical reason for this.

5 To determine the age of the nebula, you need to find the expansion rate, the amount it has expanded versus time (this is, in a sense, the speed of expansion on the sky). Given the dates of the two images (February 11, 1956 and November 10, 1999) calculate the time elapsed between them to the nearest 0.1 years. Now divide the expansion amounts or separation you calculated in Question 5 to get an expansion rate in arcseconds/year.

Are the amounts all roughly the same (within, say, 10% of each other), or is there a large variation? Why would this be?

6 Now that you have the rate of expansion, you can calculate the age of the nebula. Starting with

rate = distance / time

which can be rearranged to

time = distance / rate

use the expansion rate (in arcseconds/year) you calculated in Question 5, and the angular separation of the knots from the pulsar (in arcseconds) you found in Question 4, to calculate the age of the nebula. Use the angular separations for the 1999 image.

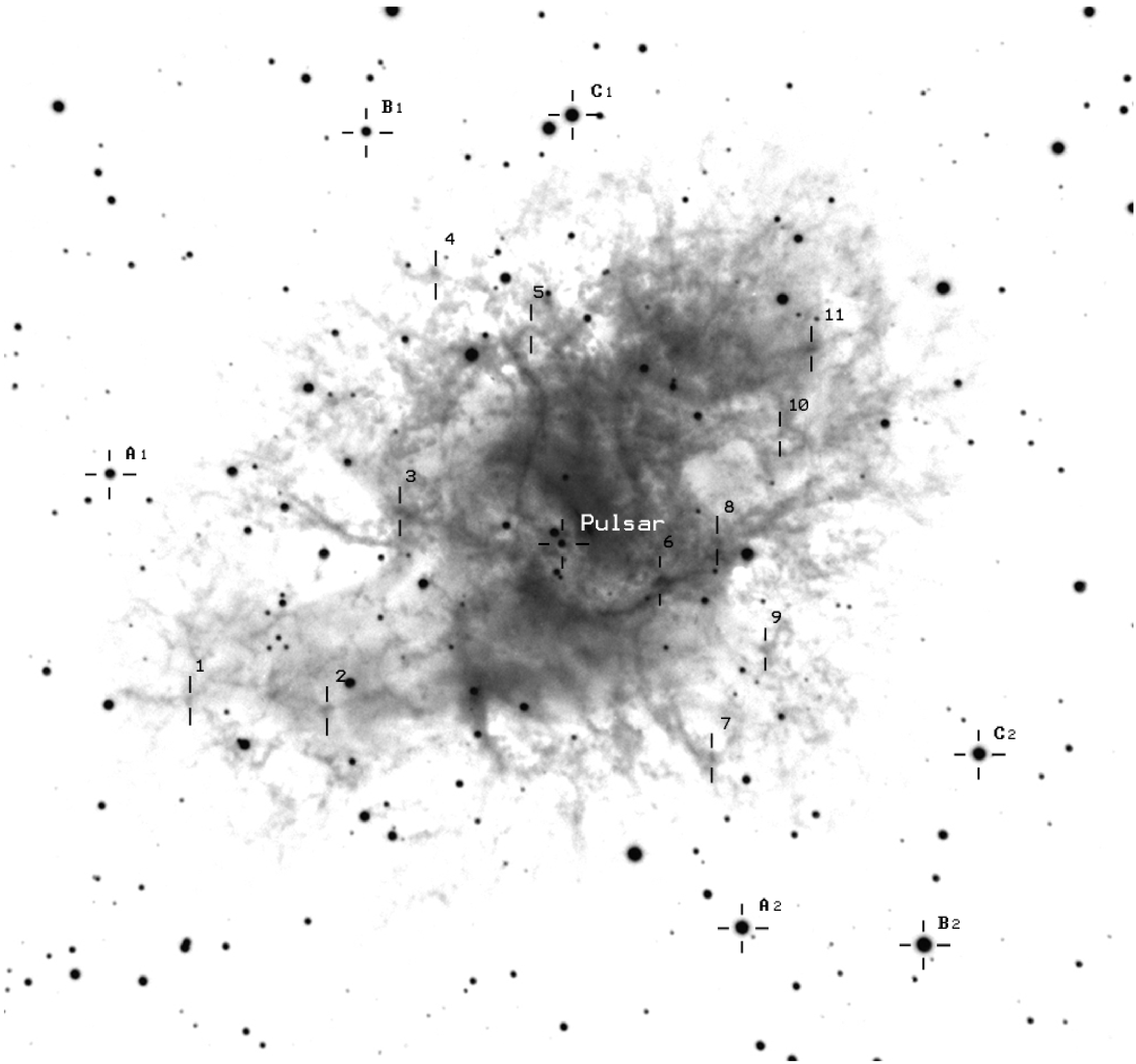
Are the ages all roughly the same (within, say, 10% of each other), or is there a large variation? Why would this be?

Calculate the median and average age of the nebula.

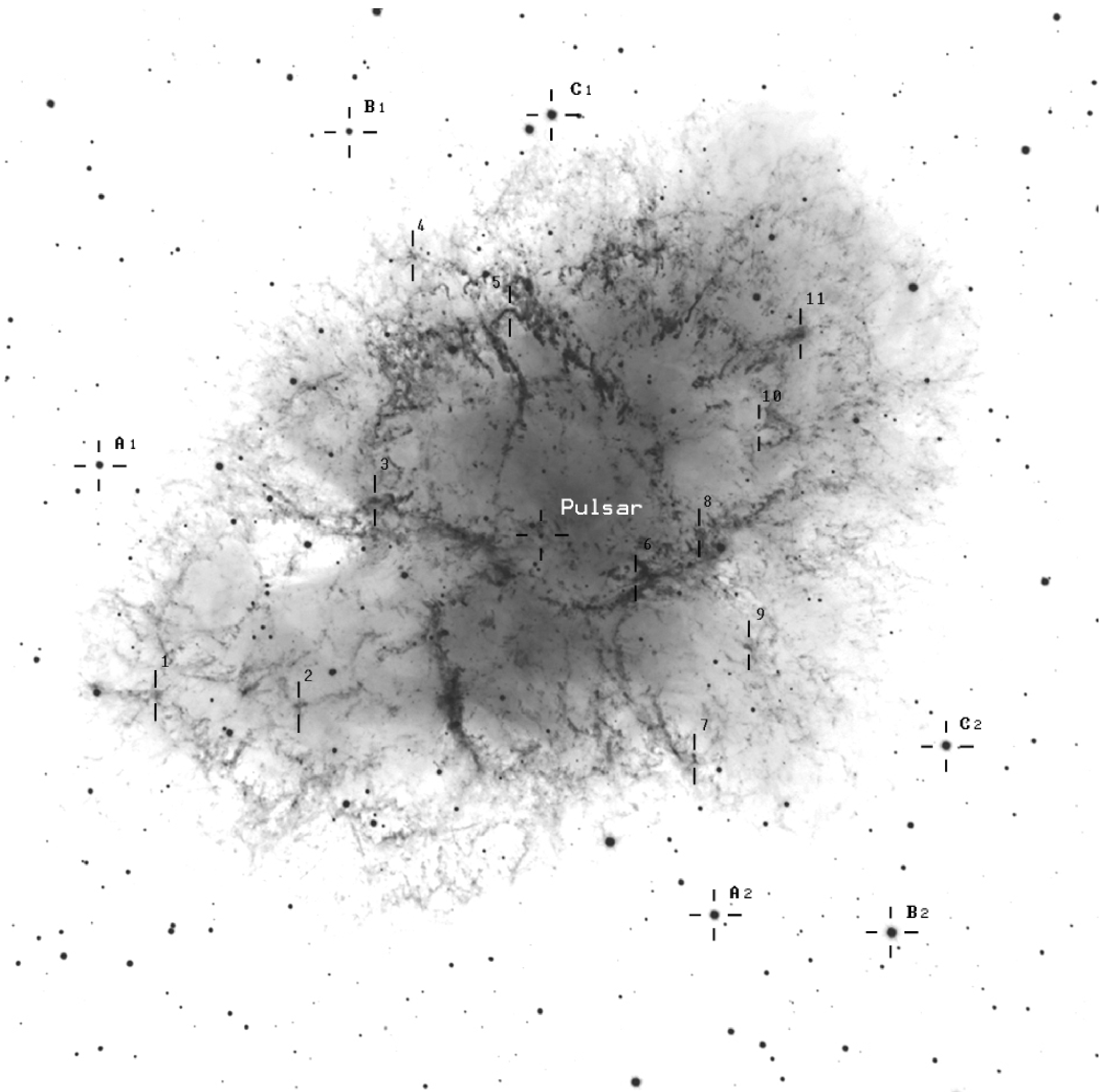
Given the date of the image you used to find the age, in what year did the star explode to form the Crab Nebula? Calculate this number for each knot, and find the median and average year.

Scientists think the star that formed the Crab nebula blew up in 1054. How close was your answer?

The Crab in 1956



The Crab in 1999



STUDENT WORKSHEET

THE CRAWL OF THE CRAB

Date: ______________________________

Name: ______________________________

1

Star Pair	Distance (cm)		Plate Scale (arcsec/cm)	
	1956	*1999*	*1956*	*1999*
A1 – A2				
B1 – B2				
C1 – C2				
		AVERAGE:		

2

knot	Distance from Pulsar (cm)		
	1956	*1999*	*Comments*
1			
2			
3			
4			
5			
6			
7			
8			
9			
10			
11			

3

knot	Separation from Pulsar (arcseconds)	
	1956	*1999*
1		
2		
3		
4		
5		
6		
7		
8		
9		
10		
11		

4

knot	Change in Separation from 1956 to 1999 (arcseconds)
1	
2	
3	
4	
5	
6	
7	
8	
9	
10	
11	

a)

b)

c)

5

knot	Expansion rate (arcseconds/year)
1	
2	
3	
4	
5	
6	
7	
8	
9	
10	
11	

5

Elapsed Time _______________ (years)

6

Knot	Age of nebula (years)	Year of the explosion
1		
2		
3		
4		
5		
6		
7		
8		
9		
10		
11		

MEDIAN: ___________ (years)

AVERAGE: ___________ (years)

MEDIAN: ___________ (years)

AVERAGE: ___________ (years)

3 THE HEART OF A SUPERNOVA EXPLOSION

Duration:
1-3 hours

Essential Questions:

- What is a neutron star?
- What is a pulsar?
- What is the relationship between neutron stars, pulsars, and supernovae?
- What are the similarities and differences between the magnetic field of a pulsar and that of the Earth?

Objectives:

Students will…

- study real news articles about XMM-Newton and learn how scientists use XMM-Newton data.
- experiment with magnets in creative ways to understand pulsars
- learn how the Earth's magnetic poles work as well as measure the period of three pulsars.
- construct and test a hypothesis about pulsars

Science Concepts:

- Neutron stars/pulsars are complex natural phenomena that combine large gravity effects with magnetic fields.
- Rotating astronomical objects, like pulsars and the Earth, have magnetic fields.
- A neutron star is the dense stellar core remaining after a supernova explosion.
- A pulsar, a spinning neutron star, has jets of light and moving particles moving.

Background information:

Most of the background information needed for this activity can be found in the article provided in the student handout. Students are assumed to have a basic knowledge of magnets and their properties. Students must know how to determine the poles of a magnet and how to draw magnetic field lines for **dipole** magnets.

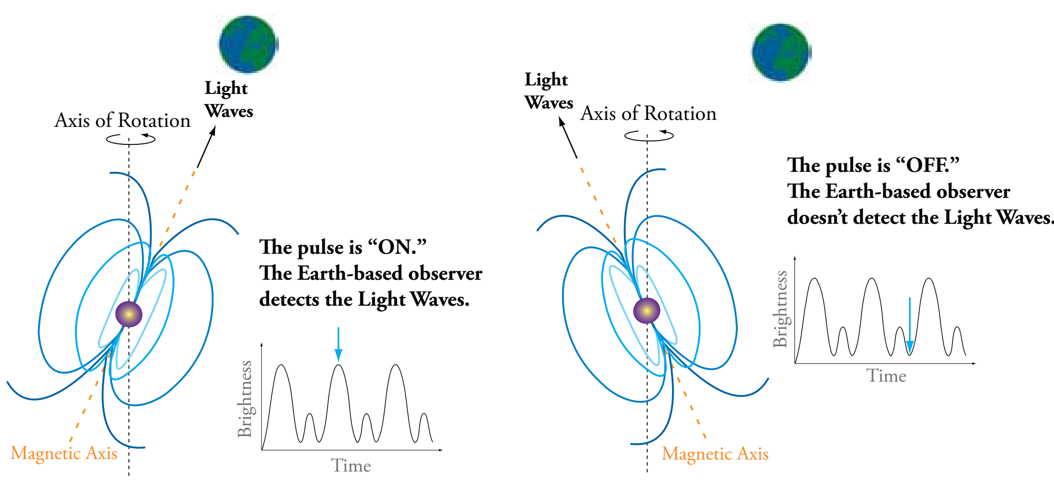
Additional information *(also see the initial introduction to this guide.)*

At the end of a star's life, what's left behind depends on the mass of the star's core. A star like the Sun is destined to become a white dwarf; a compressed ball of white-hot matter with about the mass of the Sun, but the size of the Earth. The enormous gravity of the white dwarf tries to compress it, but the star is held up by complicated quantum mechanical forces that act on electrons inside it.

However, if the core of the star is between 1.4 and 2.8 times the mass of our Sun, then the quantum mechanical forces on the electrons cannot support such a great mass, and the core collapses to what's called a neutron star. Instead of the quantum mechanical forces on the *electrons* supporting the star, similar forces on the *neutrons* support it. A neutron star is incredibly dense, with twice the mass of the Sun squeezed into a ball only a few miles across.

If the core of the star is more than about 3 times the mass of the Sun, even the forces on the neutrons can't support it. In fact, no force in the Universe can stop the collapse, and the core compresses down into the Universe's ultimate dead-end: a black hole.

This exercise is concerned with neutron stars. In fact, it deals with a specific kind of neutron star: one that spins rapidly and has a strong magnetic field. Such a neutron star is called a "pulsar".



A pulsar is a rotating neutron star that emits electromagnetic radiation and charged particles from its magnetic poles. The rotational and magnetic axises are not necessarily aligned in a pulsar. As the pulsar spins about its rotational axis, at least one of the magnetic poles sweeps through the observer's line of sight. When the magnetic pole is pointed towards the observer, increased light will be observed. When the magnetic pole is pointed away from the observer, the light will be considerably dimmer. As the pulsar spins, this creates the appearance that the neutron star is turning on and off, causing the light streaming out along the magnetic poles to appear pulsed (hence the name "pulsar").

If neutron stars are made of neutral particles, how can they have magnetic fields?

Neutron stars are not totally made of neutrons – they have a "crust" with plenty of electrons, protons, and other particles. These charged particles can maintain the magnetic field. Plus, a basic property of magnetism is that once a magnetic field is made, it cannot simply disappear. Stars have magnetic fields because they are composed of plasma, very hot gas made of charged particles. When the star collapses to become a neutron star, it retains that "relic" magnetic field. And since the star gets smaller, the magnetic field gets stronger, since in a sense the field gets denser, more compressed. That is why neutron stars not only have magnetic fields, but why they are so strong.

Procedure:

(You should read the instructions below as well as those in the student handout, as this handout contains more details.)

Note to the teacher: This is an open-ended inquiry activity. You should expect to provide minimal guidance to the students as they are doing the experiments. We advise you that it is best to repeatedly question the students, rather than providing them with the answers. This is a more effective way to teach your students to think for themselves, and to model scientific methods. This activity is divided into four sections:

A) XMM-Newton news article and analysis
B) Exploring magnets and their properties
C) Constructing a mini-model of a pulsar
D) Conclusions and debrief

Materials:

Part B:

• Many magnets. At least 2 different types (Neodymium, Samarium Cobalt, Alnico, Ceramic or Ferrite) of magnets and at least 5 different magnets of different sizes and shapes. (Check online: you can find grab bags of magnets at low prices.) Scales, compasses, and rulers. Paper and writing utensil.

Part C:

• Small spheres of different sizes (1"-2.5") and small laser lights, writing utensil and paper, rubber bouncy balls (optional), 2 diodes (available at any electronics store), small batteries (camera or laser pointer size), aluminum foil. Plastic knifes, tape, and thumbtacks.

It is recommended to do all sections of the full activity, but if you are limited in time or you are doing this with advanced students you can choose one of the various scope and sequences below.

Scope and Sequence:

	Full Inquiry	Full Inquiry Advanced Students	Guided Inquiry
A - XMM-Newton news article and analysis	Do entire section	Do entire section	Do entire section
B - Exploring magnets and their properties	Do entire section	If your students fully understand the properties of magnets this activity can be skipped or done as a demonstration.	Do Questions 5-8 as an in class demonstration. Have students answer remaining questions in groups.
C - Constructing a mini-model of a pulsar	Do entire section	Questions 18 – 30	Show the students various examples of pulsars models that can be created. Then have them make one of the examples shown and answer all questions.
D - Conclusions and debrief	Do entire section	Optional	Do entire section

Pre-class or In-class – Section A: Make one copy of the student handout for each student (p.31 & 32). You may choose to send the article home with your students the night before and have them write about it before they come to class, or you may have them read it in class (the questions and directions are located on the student handout). If you choose to have the students read the article as homework, the following day put them into groups to discuss their answers to the questions about the article. If they read it in class, have them immediately discuss the articles in groups of 3 or 4 students. Have the students in the groups record the discussion and design a presentation to report back to the class. We suggest giving each group five to ten minutes to make their presentation. Ask the students what they have learned from this article.

In-class – Section B: After completing Section A, have the students return to their groups and work together on exploring magnets and their properties. For this, we have created an effective demonstration about the magnetic fields of spherical objects. The write-up for the Magnetic Globe Demonstration is located before the student handout for this activity (p.30), and some preparation needs to be done before the demo is ready to be shown to the students; read the instructions for details. At this point we encourage you to walk around the classroom and question the students to probe their thoughts and to check their reasoning.

Let them ponder these issues for a while. Your ultimate goal is to get the students to devise a measurement system that tests the strengths of their magnets. They can do this a number of ways; see the answer section for possible measurement systems. As long as your students demonstrate clear reasoning, their answers will be correct. However, it is up to you to assess the quality of their thinking.

If your students are struggling with the magnet experiment, consider asking them questions such as:

- How could you move your magnets using other magnets?
- How do we measure other properties such as length? Mass? Light?
- How do we measure things we can't see? (one example would be electricity)

In-class – Section C: The goal of this section is for the students to learn how pulsars create pulses, and then to create mini-models of pulsars in which light from the diodes is emitted out of opposite poles of a spherical object. We encourage you to walk around the classroom and ask students questions to guide their design work. Depending on how much material is available, the students can work either as individuals or in groups to build the models and then continue answering questions from the handout for Section C. Attempt to lead them into seeing that when the light passes past their eyes it appears to be a pulse (this effect is more obvious if they shine the light on a wall and spin it). Ask the students to look at the models and try to figure out how the model can be moved to create pulses.

Some suggested questions include:

- What is a pulse from a pulsar?
- What do you see when the model spins around?
- Can you change the pulse pattern by changing the way the model is oriented?

In-class – Section D - Conclusions and Debrief: Your students may find the questions in this section challenging. They may have to do additional outside research in order to fully answer some of them. They may benefit from reading the introductory material to this educator guide, or material found on the following websites:
http://imagine.gsfc.nasa.gov/docs/science/know_l1/supernovae.html
and *http://imagine.gsfc.nasa.gov/docs/science/know_l2/pulsars.html*

Extensions:
Have your students compare the location of the earth's rotation axis and magnetic axis. How many **degrees** apart are they?

Extension question for pulsar plots (p. 39): Why are the pulses from the Vela and Crab not simple sinusoids as your model would predict? Answer: the magnetic fields are not simple dipoles, and there is emission at angles other than exactly lined up with the magnetic poles.

Assessment

Points	Part A: The Heart of a Supernova Explosion	Part B: Exploring Magnets and their Properties	Part C: The Heartbeat of a Supernova	Part D: Conclusion
4	Used the complete 10 minutes to present accurate information about the article and mentioned all 5 science topics discussed in the article.	Created a system for testing magnets' strength which another student could duplicate, and created accurate drawings of fields.	Created a mini-pulsar that looks like the instructor's sample images. Student drew clear diagrams and had thorough explanations.	Response and explanations are thorough and accurate.
3	Used the complete 10 minutes to present accurate information about the article and mentioned 3-4 science topics discussed in the article.	Created a system for testing magnets' strength which another student could duplicate, and created almost accurate drawings of fields.	Created a mini-pulsar that looks like the instructor's sample images. Student drew mostly clear diagrams and had mostly thorough explanations.	Response and explanations are mostly thorough and accurate.
2	Used at least 5 minutes to present accurate information about the article and mentioned 2-3 science topics discussed in the article.	Created a system for testing magnets' strength, which another student could mostly duplicate with guidance, and created almost accurate drawings of fields.	Created a mini-pulsar that looks somewhat like the instructor's sample images. Student drew somewhat clear diagrams and had somewhat thorough explanations.	Response and explanations are somewhat thorough and accurate.
1	Presented some accurate information about the article and mentioned at least 1 science topic discussed in the article.	Created a system for testing magnets' strength which another student could not duplicate even with guidance, and created almost accurate drawings of fields.	Created a mini-pulsar that looks somewhat like the instructor's sample images. Student drew diagrams and had incomplete explanations.	Response and explanations are completed but not accurate.
0	None turned in.	None turned in.	None turned in.	None turned in.

Answer Key - The Heart of a Supernova Explosion:

Section A:

1. This will depend on the student. Students will no doubt have a variety of questions. Encourage them to research answers further using the resources given in the appendix of this guide.

2. Students should write a clear summary here. Science topics should include
a) supernovae,
b) the XMM-Newton observatory,
c) a neutron star's magnetic field,
d) X-ray observations,
e) and/or stellar life cycles.

The reason scientists are interested in these topics is because only a few neutron stars emit X-rays directly from their surfaces, thus allowing a direct measurement of the magnetic field. Individual neutron stars are difficult to study, and not much is known about them as individual stars. They are also interested because the magnetic field is much weaker than they had previously theorized, and this means there is more to learn about this star.

3. Scientists need to observe other neutron stars in this same way to see if the one they studied was an oddball, or just one of many like it.

4. These data were published by a team of European astronomers; specifically Professor Giovanni Bignami of the Centre d'Itude Spatiale des Rayonnements (CESR) and his team. The instrument used was XMM-Newton; an X-ray observatory in space.

Section B:

5. Your student's answers will vary. While there are many possible ways to perform this experiment, having a few specific methods (and their materials) on-hand can be useful should any of the students need a little guidance. Examples are given below. We encourage you to gently nudge students towards a workable experiment as they endeavor along their own individual paths, as that helps develop scientifically-adept communication skills as well as minimizing any excessive frustration that they may feel.

Example 1:

Materials: Graph paper (4 squares per inch or more is preferable, one or two sheets per group is generally enough), pencils, several test magnets, one control magnet, one control ferrous metal bar (or any ferrous metal item). Note: Students may use either a magnet or the metal bar as the control object, though the metal bar tends to give "cleaner" results.

Set-up & Testing: There are two general ways to approach setting up this experiment.

Place the graph paper on a level surface. Then place the control (magnet or metal bar) at one edge of the graph paper and have one student hold it in place during the experiment. Note: If the students are using especially strong magnets make sure the students keep their fingers out of the way of the test magnet's path! Take a test magnet and place it at the opposite end of the graph paper.

Safety issue!: if the students are using especially strong magnets, they may have to use two pieces of graph paper taped together. Finally, very slowly push the test magnet from behind toward the control until the test magnet is attracted to the control. Record the distance at which this happens. Repeat several times for each test magnet and take the average of the results.

Example 2

Materials: A clear measuring cup, beaker (the taller the better) or tall Tupperware container, a photocopy of a ruler, tape, test magnets, control metal, string.

Set-up: Place the control metal in the beaker. Cut-out and tape the photocopy of the ruler to the side of the beaker, with 0 at the bottom of the beaker. Tie the string around your first test magnet. Slowly lower the test magnet into the beaker. Measure the point at which the control metal is attracted to the test magnet. Repeat several times for each test magnet and take the average of the results.

This can also be done without the container, just using a ruler standing on end, but it's more difficult to align the magnets well.

If the students have enough time, have them fill the beaker with water and repeat the tests. Do the results differ than those found for air?

Example 3

Materials: paper clips and ruler

Set-up: Paper clips scattered on a table top. See how many paperclips the magnet could hold, if the clips were hanging down from the magnet. Use the ruler to measure the length of the hanging paperclips or count the number of paperclips that can be hung.

6. This answer will vary from student to student.

7. The dominating characteristic in magnets is the type of magnet that is being tested. Here is the list of magnets in order of decreasing strength: Neodymium, Samarium Cobalt, Alnico, Ceramic or Ferrite. The next dominating characteristic will be the size of the magnet. The shape of the magnet should not matter, but this may be difficult for the students to determine unless they have two magnets of the same material, but with different shapes.

8. The other characteristic that helps to determine the strength of a magnet is its material composition. Question 7 lists the different common materials for magnets, there are also many other types of magnets.

9. This answer will vary from student to student (see figures 1 and 2.)

Different ways to indicate relative strength are:

- The standard way to depict magnetic field strength uses closely spaced lines where the field is strongest (e.g., the poles), with less line density in regions of weaker fields. A student may use graph paper to better illustrate and measure these spaces.
- Alternative methods would include: drawing large arrows coming out of the poles of the magnets, where a bigger arrow or a thicker line indicates a region with a stronger field
- The students could color code the regions, with a particular color sequence indicating regions of stronger fields changing to weaker fields.

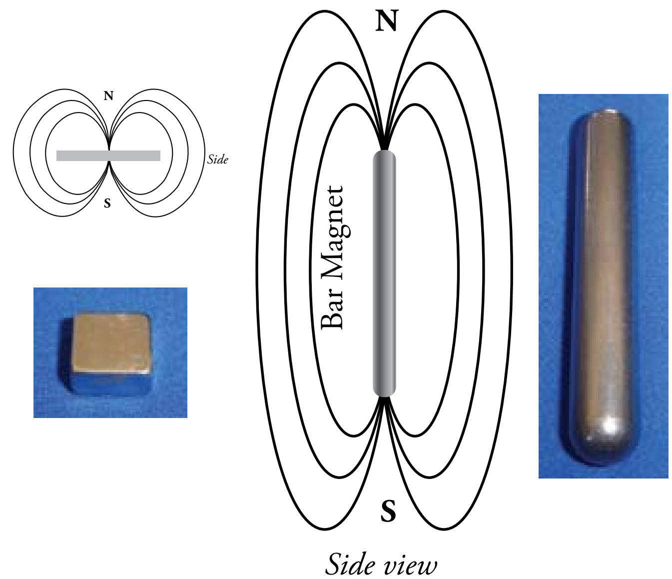


Figure 1: Possible drawings to represent field lines.

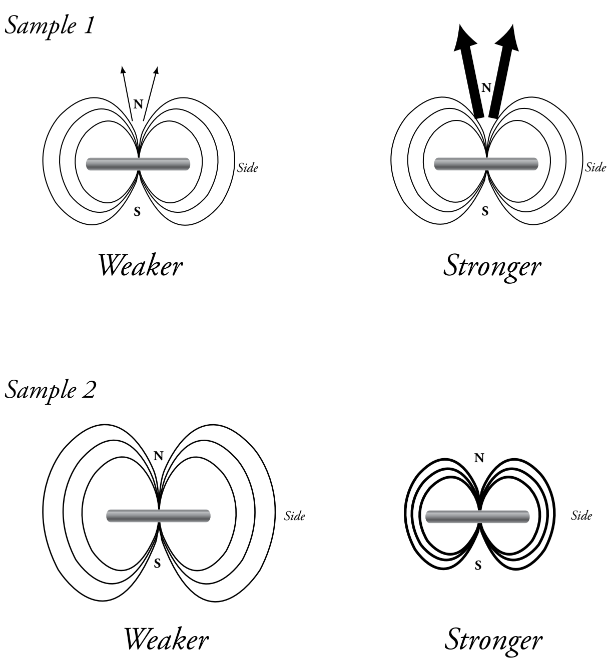


Figure 2: Possible drawings that students may draw to show relative strengths

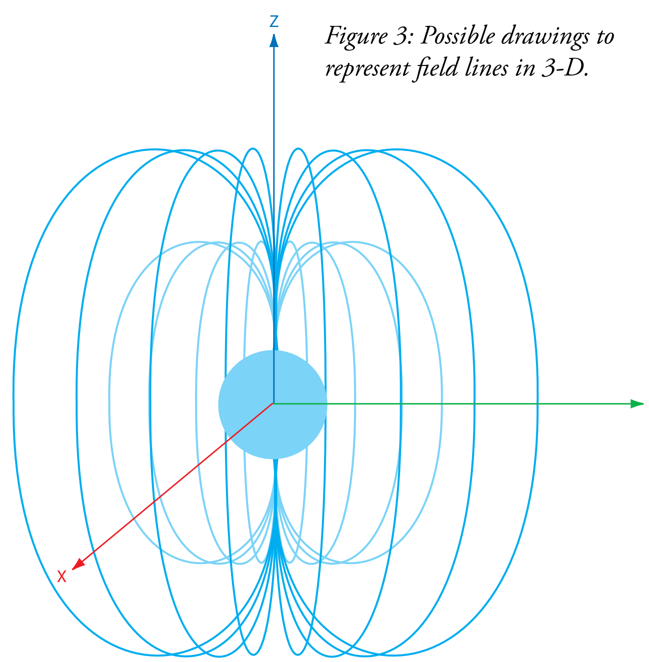


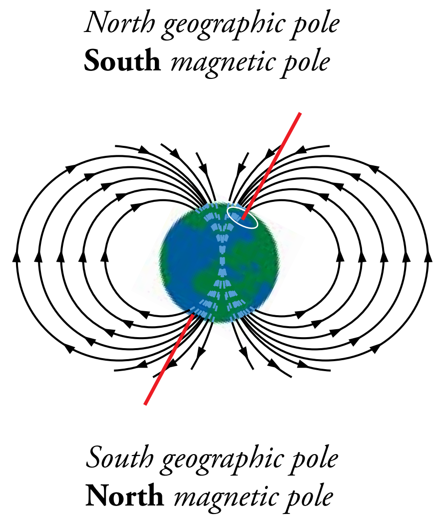
Figure 3: Possible drawings to represent field lines in 3-D.

10. As in question 9, the students will have a various interpretations of the field lines in 3-D. See Figure 3 for one possible way to do this.

11. The Earth.

12. Sample diagram figure 4 to rhe right.

Figure 4



13. This answer will vary from student to student. Most students' answers to the previous question will most likely be wrong at first.

14. The magnetic field strength would increase because the field lines would be squeezed together. In other words, the magnetic field would be more concentrated than it was in the previous larger star.

15. The magnetic field of a pulsar is a trillion times that of the Earth.

16. See table below:

Object	**Strength (Gauss)**	**Radius (km)**	**Area (km²)**	**Flux (G/km²)**
Galactic magnetic field	1.00×10^{-5}	1.50×10^{10}	2.83×10^{21}	3.54×10^{-27}
Solar Wind	5.00×10^{-5}	1.50×10^{10}	2.83×10^{21}	1.77×10^{-26}
Interstellar molecular cloud	1.00×10^{-3}	5.70×10^{14}	4.08×10^{30}	2.45×10^{-34}
Earth's field at ground level	1.00	6.40×10^{3}	5.15×10^{8}	1.94×10^{-9}
Solar surface field	5.00	6.95×10^{5}	6.07×10^{12}	8.24×10^{-13}
Simple iron bar magnet	1.00×10^{2}	1.00×10^{-2}	1.26×10^{3}	7.96×10^{4}
Jupiter field	1.00×10^{3}	7.10×10^{4}	6.33×10^{10}	1.58×10^{-8}
Magnetic Stars	1.20×10^{4}	1.50×10^{6}	2.83×10^{13}	4.24×10^{-10}
White Dwarf star surface	1.00×10^{6}	6.40×10^{3}	5.15×10^{8}	1.94×10^{-3}
Neutron star surface	1.00×10^{12}	1.00×10^{1}	1.26×10^{3}	7.96×10^{8}
Magnetars	1.00×10^{15}	1.00×10^{1}	1.26×10^{3}	7.96×10^{11}

17. A large spherical object like a star collapsed into a smaller sphere squeezes the magnetic field along with it into a smaller sphere. The magnetic field at any given place would therefore be stronger because that location would now have a greater density of magnetic field lines.

Section C: The Heartbeat of a Supernova

18. This answer will vary from student to student. One possible answer is "The above paragraph talks about how a neutron star spins. As the pulsar spins about its rotational axis, at least one of the magnetic poles sweeps through the observer's line of sight. When the magnetic pole is pointed towards the observer, increased light will be observed."

19. As the pulsar spins about its rotational axis, at least one of the magnetic poles sweeps through the observer's line of sight. When the magnetic pole is pointed towards the observer, increased light will be observed. When the magnetic pole is pointed away from the observer, the light will be considerably dimmer.

20. See drawing in teacher's background information (p.22). Note: the students are not expected to draw the graphs.

21. The laser light represents the poles of the magnetic field where the beam of light is emitted from the neutron star.

22. The model sends out light continuously, but we see pulses as the light emitter sweeps past our eyes as the model spins.

23. This means that the pulsar spins completely around its rotational axis at a rate of once every 40 milliseconds.

24. See drawing in teacher's background information (p.22). The difference between this diagram and the one in question 20 is that this one is a drawing of the pulsar the students designed and it also should show the magnetic field lines of the neutron star.

25. There are many misrepresentations in this model as there are always with models of large objects. Such misrepresentations includes: size, materials used, magnetic field lines are invisible to the eye, and the object is continually spinning.

26. See drawing in teacher's background information (p.22).

27. The pulsed light emitted from the pulsar is emitted along the poles of the magnetic field.

28. There are several reasons this might occur:

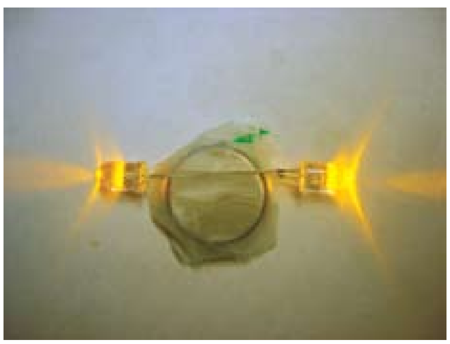
- scientists may not be able to view the light from a neutron star because dust and gas is obscuring light.
- scientists may not see the light emitted from a neutron star because the object is being viewed in the wrong wavelength of light.
- The spin axis of the star may be point right at us, or 90 degrees away, with the magnetic field aligned with it. In that case, one magnetic pole is always visible and no pulsing would occur.

29. The pulse period tells scientists how fast the neutron star spins on its rotational axis.

30. The period of the Vela pulsar is ~94 milliseconds. The period of the Crab pulsar is ~33 milliseconds.

Note: The pulse for each pulsar in question 30 is a double pulse. One period is represented here by the repeated sets, not the individual sinusoids.

Two pulsar prototypes your students may design:



First step:
two diodes simply taped
to a camera battery

You can then encase
them using modeling
clay, or...

... you can wrap them
in aluminum foil.

Section D - Conclusions and Debrief

31. Scientists study supernovae and pulsars to gain a better understanding of the stellar life cycle. They also gain a better understanding of the physical world around us by studying these massive objects. Another reason may be because the supernovae act as a lab that creates extreme physical conditions that can't be duplicated on Earth.

32. By studying these objects, scientists may learn more about strong magnetic fields and how matter behaves under their influence, conditions which cannot be recreated on labs on Earth.

33. A supernova explosion is the end of the life of a massive star. A neutron star can form in the core of a supernova.

34. Supernova explosions blast heavy elements such as iron, oxygen, and calcium into space. These elements can then "seed" forming stars, and be incorporated into the planets, moons, and other objects that form around the stars.

35. This answer will vary from student to student.

MAGNETIC GLOBE DEMO

Materials:

- 1 – 2.5” diameter foam rubber Earth Globe (can be any similar foam rubber ball)
- 1- neodymium magnet – 1” sphere or cube
- Exacto or other very sharp cutting knife
- 2 or 3 pins with round plastic heads
- ~100 “clamped” staples (i.e., staples that have been produced by a stapler as if they were going through paper, except without the paper)

Globe Assembly:

1. Using the knife, cut a small (approximately one inch) slit to the center of the globe.

2. Insert the magnet into the center of the sphere.

3. Align the poles of the magnet as closely as possible to the correct orientation of the Earth’s real magnetic poles. This can be done by placing about 3 “clamped” staples on each end of the globe, then moving them over the sphere until they stick out almost straight off of the globe. Another way to determine the poles is by using a compass just as you would to find the real Earth’s poles. Place the compass against the globe, and follow the needle to the north pole. Once you have located the poles, rotate the magnet until the north pole is in the approximate location of the Queen Elizabeth Islands.

4. Seal up the seam on the rubber ball using two or three pins with plastic heads to bind the sides together as one would with fabric.

5. Slowly drop the “clamped” staples on the sphere, placing them so that they do not criss-cross along the latitude direction of the Earth globe. Make sure your globe looks like the image shown here.

What this globe ball demonstrates:

The staples provide a three dimensional representation of the magnetic field lines of our Earth. Our Earth’s magnetic field is a configuration known as a “dipole field.” This type of field is also observed from common magnets, such as bar magnets, but most representations of this field configuration appear in textbooks or are done on pieces of paper using iron filings, and therefore are only experienced in two dimensions.

Many objects in space have dipole magnetic fields that are geometrically similar to that of the Earth. However, the strength of magnetic dipole fields in space vary dramatically – from fractions of a Gauss (solar surface) to billions of Gauss (magnetic white dwarf stars.) The most extreme magnetic fields in the Universe are seen from neutron stars known as magnetars (approximately one thousand trillion or 10^{15} Gauss). The strength of the magnetic field is proportional to the density of field lines in a given region: areas with a greater density of field lines have stronger fields. In this case, the field lines are represented by staples and so the field is stronger where the staples are closer together.

Using the magnet in the globe you can show your students that a stronger magnetic field source will have the staples aligned closer to each other. To properly demonstrate this, the magnet must be spherical in shape. Use a second magnet, or pull the magnet out of the foam rubber globe, and repeat the experiment with the staples placed directly on the magnet.

Resources:
See appendix

In the News

11 June 2003

XMM-Newton makes the first measurement of a dead star's magnetism

Using the superior sensitivity of ESA's X-ray observatory, XMM-Newton, a team of European astronomers has made the first direct measurement of a neutron star's magnetic field. The results provide deep insights into the extreme physics of neutron stars and reveal a new mystery yet to be solved about the end of this star's life.

A neutron star is a very dense celestial object that usually has something like the mass of our Sun packed into a tiny sphere only 20-30 kilometres across. It is the product of a stellar explosion, known as a supernova, in which most of the star is blasted into space, but its collapsed heart remains in the form of a super-dense, hot ball of neutrons that spins at a incredible rate.

Despite being a familiar class of object, individual neutron stars themselves remain mysterious. Neutron stars are extremely hot when they are born, but cool down very rapidly. Therefore, only few of them emit highly energetic radiation, such as X-rays. This is why they are traditionally studied via their radio emissions, which are less energetic than X-rays and which usually appear to pulse on and off. Therefore, the few neutron stars which are hot enough to emit X-rays can be seen by X-ray telescopes, such as ESA's XMM-Newton.

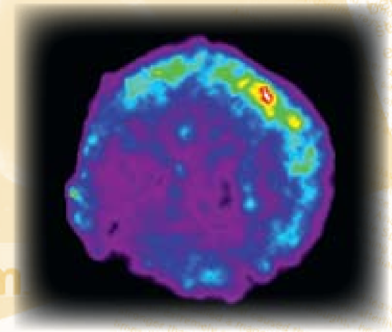
One such neutron star is 1E1207.4-5209. Using the longest ever XMM-Newton observation of a galactic source (72 hours), Prof. Giovanni Bignami of the Centre d'Itude Spatiale des Rayonnements (CESR) and his team have directly measured the strength of its magnetic field. This makes it the first ever isolated neutron star where this could be achieved. All previous values of neutron star magnetic fields could only be estimated indirectly. This is done by theoretical assumptions based on models that describe the gravitational collapse of massive stars, like those which lead to the formation of neutron stars. A second indirect method is to estimate the magnetic field by studying how the neutron star's rotation slows down, using radio astronomy data.

XMM-Newton

In the case of 1E1207.4-5209, this direct measurement using XMM-Newton reveals that the neutron star's magnetic field is 30 times weaker than predictions based on the indirect methods.

How can this be explained? Astronomers can measure the rate at which individual neutron stars decelerate. They have always assumed that 'friction' between its magnetic field and its surroundings was the cause. In this case, the only conclusion is that something else is pulling on the neutron star, but what? We can speculate that it may be a small disc of supernova debris surrounding the neutron star, creating an additional drag factor.

The result raises the question of whether 1E1207.4-5209 is unique among neutron stars or the first of its kind. The astronomers hope to target other neutron stars with XMM-Newton to find out.



Tycho Supernova remnant, XMM-Newton, 2006

X-rays emitted by a neutron star like 1E1207.4-5209, have to pass through the neutron star's magnetic field before escaping into space. En route, particles in the star's magnetic field can steal some of the outgoing X-rays, imparting on their spectrum tell-tale marks, known as 'cyclotron resonance absorption lines'. It is this fingerprint that allowed Prof. Bignami and his team to measure the strength of the neutron star's magnetic field.

These results were published on the 11 June 2003 issue of Nature.

In the News - *by* ______________________

Issue date: ______________

Directions: Read the article p.31 and as a group answer the questions in Section A on a separate sheet of paper. Then in the same groups, continue the experiments in Sections B and C, answering the remainder of the questions in this handout in your science notebook or on loose paper. The materials needed for these sections will be made available by your teacher.

1 **Author's Investigation:** *(my questions about the material discussed in this article)*

2 **XMM-Newton - Dead Star's Magnetism in Brief:**
(Using your own words, summarize the information in this article. Don't forget to include the science topics discussed and why scientists are interested in these topics.)

3 **Author's Point of View:**
(Predict other types of measurements scientists will try to make?)

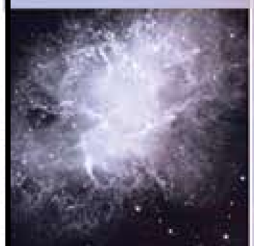
4 **People and Science:**
(Who are the scientists that did the work discussed in this article? What instruments did they use?)

Let's Talk:

In discussion groups, *use your individual responses to discuss the answers to the above questions. Choose one person in the group to record this discussion. Design a brief presentation to report back to the class. You will only have 5 minutes for your presentation. Be creative!*

Section B – *Exploring Magnets and Their Properties:*

The above article mentioned two defining characteristics about neutron stars: they have strong magnetic fields, and they spin rapidly. Let's see if we can understand how these two properties work together to create pulsars.



5 Can you devise a system to measure a magnet's strength? Create one method and write instructions so that other students can use your system to repeat the measurements. Test all of your magnets and record your findings using your system.

6 Now have someone else in your group repeat your method to measure the magnets. How well did the results agree? Did you need to modify your instructions so that your partner could accurately repeat your experiment?

7 What characteristics of your magnets seem to determine their strength? Size? Shape? Anything else?

8 What other characteristics of magnets help determine its strength?

Determine the north and south poles on your magnets.

9 Draw a diagram illustrating the magnetic fields lines around each magnet and label their poles. How can you indicate the relative strengths of each pole?

Now imagine you have a spherically shaped dipole magnet (you can also imagine this as being a bar magnet embedded in a spherical object)

10 Where do you think the poles would be now? Draw what you think the field lines would look like in three dimensions.

11 Can you think of an example of an object that you see on an every day basis that may have this type magnetic field?

Answer

12 Add a diagram of the Earth that shows its magnetic field lines and poles and label your poles.

13

Research: Go online and search for information about the Earth's magnetic poles. (Also, try to think about how a compass works: what type of pole is at the north geographic pole of the Earth?) Were you correct about what you designated as your North and South poles?

14

Now imagine that the spherical object the size of the Earth collapses down until it is the size of a city. Assuming that the collapse does not affect the total number of magnetic field lines, what would happen to the magnetic field?

15

In the table p.36, you will see a list of objects with their magnetic strength listed to the right. How does the magnetic field strength of a pulsar compare to that of the Earth?

16

Notice that there are some missing data in the table p.36. Compute the area ($4\pi R^2$) and flux for these objects:

$$\left(\text{Flux} = \frac{\text{Strength of field (B)}}{\text{Area}} \right)$$

17

Does this help you to understand why neutron stars have such strong magnetic fields? Explain.

Object	Strength (Gauss)	Radius (km)	Area (Km^2)	Flux (G/Km^2)
Galactic magnetic field	1.00×10^{-5}	1.50×10^{10}	2.83×10^{21}	3.54×10^{-27}
Solar Wind	5.00×10^{-5}	1.50×10^{10}	2.83×10^{21}	1.77×10^{-26}
Interstellar molecular cloud	1.00×10^{-3}	5.70×10^{14}	4.08×10^{30}	2.45×10^{-34}
Earth's field at ground level	1.00	6.40×10^{3}		
Solar surface field	5.00	6.95×10^{5}	6.07×10^{12}	8.24×10^{-13}
Simple iron bar magnet	1.00×10^{2}	1.00×10^{-2}		
Jupiter field	1.00×10^{3}	7.10×10^{4}	6.33×10^{10}	1.58×10^{-8}
Magnetic Stars	1.20×10^{4}	1.50×10^{6}	2.83×10^{13}	4.24×10^{-10}
White Dwarf star surface	1.00×10^{6}	6.40×10^{3}	5.15×10^{8}	1.94×10^{-3}
Neutron star surface	1.00×10^{12}	1.00×10^{1}		
Magnetars	1.00×10^{15}	1.00×10^{1}		

Table 2

Section C - The Heartbeat of a Supernova

You may recall in the article about the XMM-Newton mission that a supernova is the result of a stellar explosion. While the outer layers of the star explode outward, the core of the star collapses into a very hot dense ball of neutrons referred to as a neutron star. In many cases, neutron stars can be seen “pulsing” rays of light and particles. When we observe this pulsing, they are called pulsars..

A pulsar is a rotating neutron star that emits rays of light and charged particles along its magnetic poles. The rotational and magnetic axises are not necessarily aligned in a pulsar. As the pulsar spins about its rotational axis, at least one of the magnetic poles sweeps through the observer's line of sight. When the magnetic pole is pointed towards the observer, increased light will be observed. When the magnetic pole is pointed away from the observer, the light will be considerably dimmer. The spinning neutron star creates the appearance that the pulsar is turning on and off; causing the light streaming out along the magnetic poles to appear pulsed.

18 Did the above paragraph tell you anything about supernovae that you didn't already know? Explain.

19 What makes a pulsar pulse?

20 Draw a schematic that illustrates how a pulsar "pulses." In this diagram indicate the intensity of the light that would be observed at different points as the neutron star rotates.

Sketch

Experiment: Using the materials provided; design and create a model of a pulsing neutron star. Describe it on the next page.

Suggested Materials:

- **Small laser lights**
- **Rubber bouncy balls**
- **Diodes**
- **Plastic knives**
- **Thumbtacks**
- **Tape**
- **Small thin wire**
- **Small batteries (3 V)**
- **Modeling clay**
- **Aluminum foil**

21 What does the laser light represent on your model neutron star?

22 How does your model create pulses?

23 A pulsar has a pulse period of 40 milliseconds. Explain what the pulse period represents.

24 Based on the model that you just made, draw a schematic of your pulsing neutron star. Remember what you already know about neutron stars from before. Hint: There are things that you should show on your schematic that you can not see with your eyes.

Looking at the schematic of your pulsar

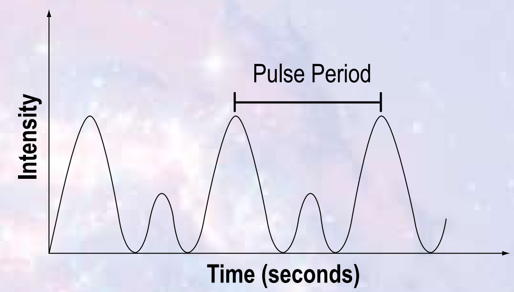
25 What characteristics of your model pulsing neutron star are misrepresented or missing?

26 What are the different components on your model pulsing neutron star that make it uniquely a pulsar? (Remember all of the characteristics of the neutron stars and pulsars that we have learned about so far.) ***Label your schematic.***

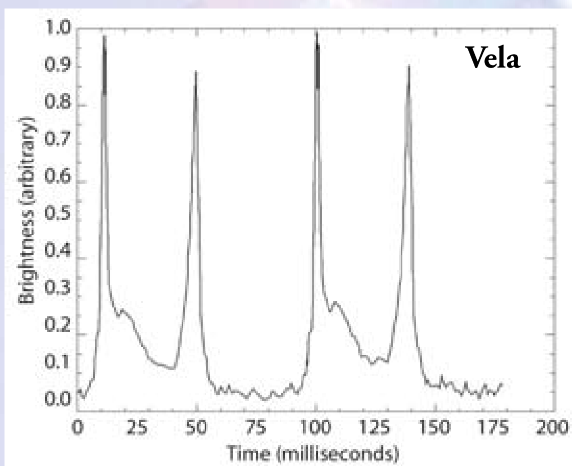
27 What is the relationship between the magnetic field lines and the pulses from the pulsar? Explain.

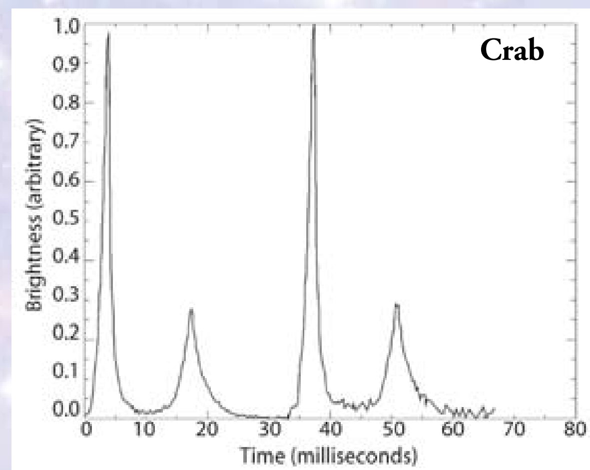
28 Can you think of at least one reason why you might not see pulses even though the neutron star is emitting beams of light and is rotating?

29 What does the pulse period tell us about the pulsar?



30 Below are plots showing light received from two real pulsars: the pulsar in Vela and the Crab pulsar. Determine the pulse period for each pulsar.





Vela pulse period:

Crab pulse period:

Section D - Conclusion and Debrief

31 Why do scientists want to study supernovae and pulsars?

My Journal

32 What insights might be gained in studying these objects?

33 How do supernovae and pulsing neutron stars fit into the life cycle of stars?

34 What effects do supernovae have on the potential for life on other planets?

35 What do you know now that you did not know before?

APPENDIX A

GLOSSARY

A

Arcsecond: an angular unit of measurement. There are 360 degrees in a circle, 60 arcminutes in a degree, and 60 arcseconds in an arcminute.

Atom: the basic unit of an element composed of a nucleus made of protons and neutrons, and an outer cloud of electrons.

B

Black hole: One type of black hole is formed from the collapsed core of a star after it goes supernova. Its gravity is so intense not even light can escape from inside the event horizon.

D

Degree: a coordinate on the sky corresponding to latitude on the Earth.

Dipole: an object (such as a magnet) that has two opposite poles separated by some distance.

E

Electron: a negatively charged subatomic particle.

G

Galaxy: a collection of gas, dust, and billions of stars bound together by their own gravity.

Gamma Ray: a very high energy photon (particle of light).

Gravity: the force exerted by one massive body on another. The force of gravity from an object depends on its mass and inversely on how far you are from it.

I

Interstellar Medium: the gas and dust that exist between the stars.

K

Knot: a small region of gas in a nebula that has a higher density than the gas around it.

L

Light curve: a plot of the brightness of an object versus time.

Light year: the distance light travels in one year; approximately 9.5 trillion (9.5×10^{12}) kilometers.

Luminosity: the total energy emitted by an object per second.

M

Magnetic pole: Either of two regions usually near opposite ends of a magnet where the magnetic intensity is greatest.

Magnitude: a brightness scale used by astronomers to measure stars. It is a logarithmic scale, where the difference in magnitudes is actually a brightness factor of 2.512.

N

Neutron: a uncharged subatomic particle that, along with protons, make up atomic nuclei.

Neutron star: the extremely dense core of a star after it has exploded as a supernova. A neutron star has a mass of 1.4 solar masses to as much as three times the mass of the Sun, but may be only a few kilometers across.

Nucleus (*plural: nuclei*)**:** the core of an atom, generally made up of protons and neutrons.

O

Orbit: the path an object takes when it is influenced by the gravity of another object.

P

Photon: an individual quantum or particle of light.

Plate scale: the units of measurement of an image or picture, usually measured as arcseconds/pixel or arcseconds/centimeter. This is analogous to the scale of a road map in kilometers/centimeter or miles/inch.

Pulsar: a rapidly rotating neutron star with a strong magnetic field, which emits twin beams of energy that sweep through the observer's field of view like beams from a lighthouse.

R

Radioactivity: a form of instability in nuclei of certain isotopes which causes them to spontaneously change their structure and to emit radiation in so doing.

S

Solar Mass: a unit of mass where the mass of the Sun is 1. Generally used for the mass of stars and galaxies. One solar mass is 2×10^{30} kg.

Solar System: a collection of planets, moons, comets, etc. which orbits a star. Our solar system is roughly 10^{10} kilometers (10^{13} meters) across.

Supernova (*plural: supernovae*)**:** the titanic explosion of a massive star at the end of its life. The outer layers explode outward, creating a supernova remnant, while the inner core collapses to become a neutron star or black hole.

Supernova remnant (SNR): the expanding gas left over from a supernova.

W

White dwarf: the dense core of a star like the Sun as it ends its life. A white dwarf has as much mass as the Sun, but the diameter of the Earth.

X

X-ray: a high energy photon (particle of light).

Additional Resources

Activity 1

Astronomy Notes: "The Lives and Deaths of Stars:"
http://www.astronomynotes.com/evolutn/chindex.htm

Bad Astronomy: "The History of Supernova 1987A:"
http://www.badastronomy.com/bitesize/sn87a_discovery.html
http://www.badastronomy.com/bitesize/sn87a_timeline.html

Imagine the Universe! "Stellar Evolution and Supernovae:"
http://imagine.gsfc.nasa.gov/docs/science/know_l2/stars.html
http://imagine.gsfc.nasa.gov/docs/science/know_l2/supernovae.html

NASA's Observatorium: "Stellar Death:"
http://observe.arc.nasa.gov/nasa/space/stellardeath/stellardeath_3.html

"The Lives and Deaths of Stars" (for advanced students):
http://brahms.phy.vanderbilt.edu/%7erknop/classes/a102/fall2003/handouts/stlrev.pdf

Wikipedia entry for stellar evolution:
http://en.wikipedia.org/wiki/Stellar_evolution

Activity 2

History of the Crab Nebula:
http://www.seds.org/messier/more/m001_sn.html and http://www.seds.org/messier/m/m001.html

Wikipedia:
http://en.wikipedia.org/wiki/Crab_Nebula

Animation of Crab expansion:
http://antwrp.gsfc.nasa.gov/apod/ap011227.html

Hubble press release:
http://hubblesite.org/newscenter/newsdesk/archive/releases/1996/22/

Bitesize Astronomy:
http://www.badastronomy.com/bitesize/crab_expand.html and http://www.badastronomy.com/bitesize/crab_pulsar.html

Activity 3

For more activities about Supernovae see:
http://xmm.sonoma.edu/edu/supernova
Imagine the Universe:
http://imagine.gsfc.nasa.gov/docs/science/know_l1/supernovae.html http://imagine.gsfc.nasa.gov/docs/science/know_l2/pulsars.html.

More about the Earth's Magnetic Field see:
http://liftoff.msfc.nasa.gov/academy/space/mag_field.html
Wikipedia:
http://en.wikipedia.org/wiki/Earth's_magnetic_field

References

Activity 1

No reference.

Activity 2

"Laboratory Exercises in Astronomy – The Crab Nebula", Owen Gingerich, Sky and Telescope magazine, November 1977, p. 378.
"The Crab Nebula", Julia Plummer and Shannon Murphy, University of Michigan, 2003.
http://helios.astro.lsa.umich.edu/Course/Labs/crab/crab-full.html

"The Crab Nebula", a lab exercise written by Brent Studer, Kirkwood (Iowa) Community College, 2006.
http://www.avalon.net/~bstuder/crab_lab.html

Crab Nebula image (1956) © 1990-2002, Malin/Pasachoff/Caltech, photograph from Hale 5-meter plates by David Malin.
Crab Nebula image (1999) © 1999, European Southern Observatory, photograph by Richard Hook and Robert Fosbury.
http://www.eso.org/outreach/gallery/vlt/images/Top20/Top20/top1.html

Activity 3

"Neutron Stars and Pulsars"
http://imagine.gsfc.nasa.gov/docs/science/know_l1/pulsars.html

"Gene Smith's Astronomy Tutorial, Supernovae, Neutron Stars & Pulsars"
http://cassfos02.ucsd.edu/public/tutorial/SN.html

Wikipedia entry for supernova
http://en.wikipedia.org/wiki/Supernova

"What is the strongest magnetic field ever known?"
http://www.astronomycafe.net/qadir/ask/a11654.html

"Neutron Stars and Pulsars"
http://www.eclipse.net/~cmmiller/BH/blkns.html

"The Crab Pulsar"
http://csep10.phys.utk.edu/astr162/lect/pulsars/pulsars.html

"ESA's XMM-Newton makes the first measurement of a dead star's magnetism" - ESA press release, June 2003.
http://www.esa.int/esaCP/Pr_38_2003_p_EN.html